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GENERAL INDEX

Erratum. On page 433, line 31 should read:

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THE CHUTE À CARON HYDRO-ELECTRIC DEVELOPMENT*

By James W. Rickey†

Introduction. Aluminum is extracted from an aluminous rock, known as bauxite, by an electrolytic process requiring large amounts of electrical energy. To meet the ever widening demand for aluminum, notably in the form of light and strong structural alloys, the two North American producers of virgin aluminum are engaged in an extensive program of plant expansion, and, by the nature of the reduction process, these plans primarily involve increases in the required supplies of electrical energy. To this end is being developed one of the largest water-power sites in the world. Known as Chute à Caron, this development is located in the Province of Quebec on the Saguenay River, 80 miles above its confluence with the St. Lawrence and 25 miles below Lake St. John. It is within 20 miles of deep-water navigation at Ha Ha Bay. (See Fig. 1.)

This project is part of a general program begun in 1925 when the Aluminum Company of America was attracted to this region by the combined advantages of cheap electric power and easy access to the ocean trade routes of the world. The Aluminum Company of Canada (then a subsidiary of the Aluminum Company of America, but later sold to a Canadian firm, Aluminium, Limited) entered the territory to build a large reduction plant and an industrial village known as Arvida. (See Fig. 2.)

At that time the 540,000-horse-power Ile Maligne project on the Saguenay River, seven miles below Lake St. John, was being completed by the Quebec Development Company, a subsidiary of the Duke-Price interests. This station now continuously supplies 100,000 horse-power to Arvida; an equal amount is transmitted 140 miles to the city of Quebec by the Shawinigan Water and Power Company for public service; and the remainder of the Ile Maligne output is absorbed by nearby pulp-mills and paper-mills.

Bauxite for Arvida is brought from South America by boat directly to Port Alfred, located on the Saguenay at Ha Ha Bay, and thence by a short rail haul to the aluminum works. The village of

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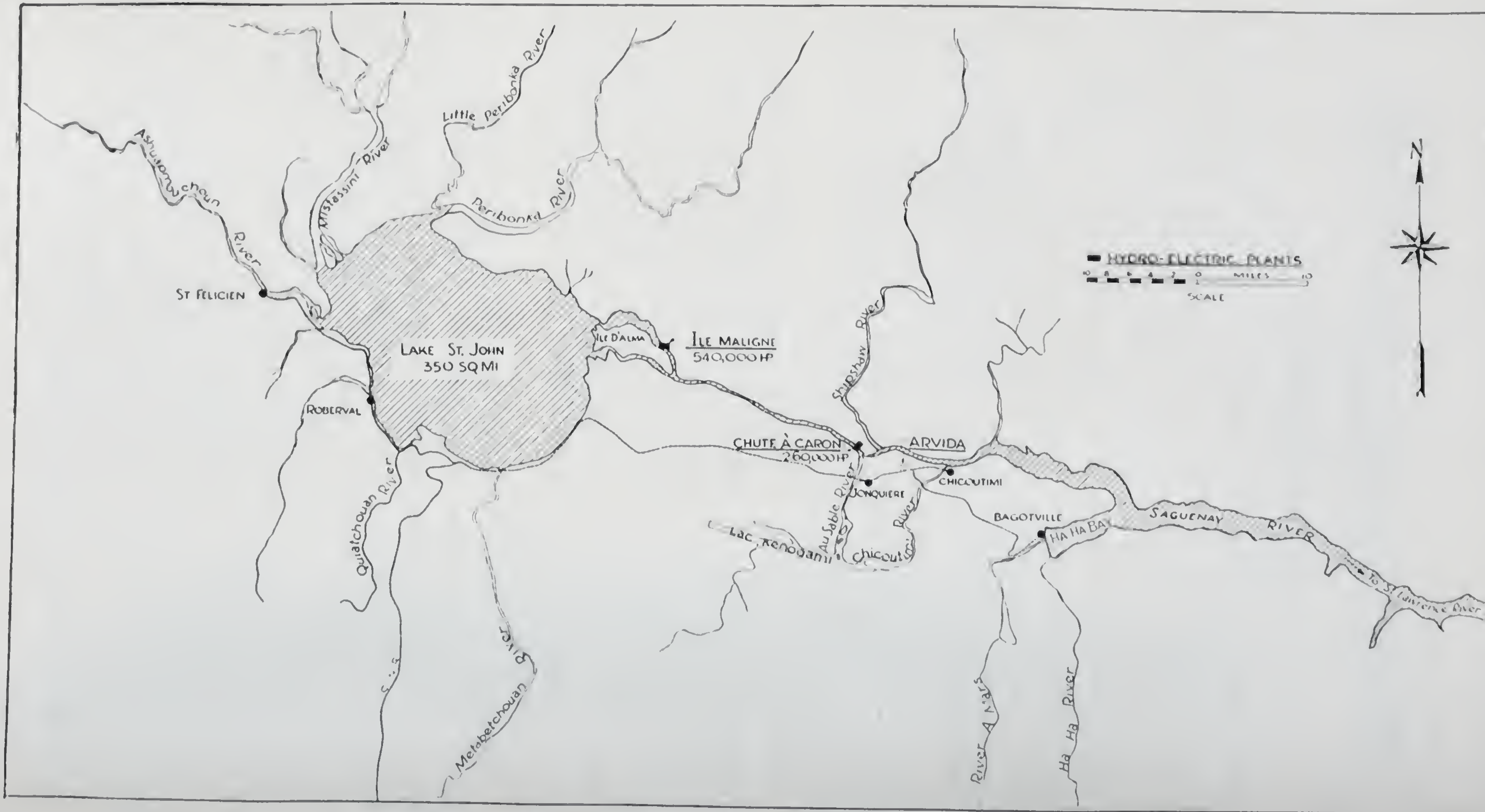

Fig. 1. Map of Saguenay River and Lake St. John District.

Arvida now has a population of about 4000 and has been laid out in accordance with the best practice in town planning, so that an ultimate growth to 35,000 inhabitants may be accommodated.

Fig. 2. Arvida Plant of Aluminum Company of Canada.

The Saguenay River. The drainage basin of the Saguenay River is not accurately mapped nor is its area accurately known, but it is estimated to be at least 30,000 square miles. The maximum flow into Lake St. John during the period recorded 1913-1930, occurred in 1928, when it was 405,000 second feet. Due to the regulating effect of this lake, which has an area of about 350 square miles and a useful storage capacity of 220,000,000,000 cubic feet (5,000,000 acre-feet) below the normal maximum level, the corresponding outflow was only 326,000 second feet. The minimum outflow from the lake is approximately 20,000 second feet. The regulated flow for power purposes is about 35,000 second feet. (See Fig. 3.)

The total fall in the Saguenay from Lake St. John to tidewater at Chicoutimi, the head of shallow navigation, is about 322 feet, nearly all of which is concentrated in falls and rapids of the first 32 miles of the river below Lake St. John. Between Chicoutimi and Ha Ha Bay the river is wide and comparatively shallow. Below Ha Ha Bay the river runs in a submerged gorge, which extends to its confluence with the St. Lawrence River and in places is more than 800 feet deep.

Chute à Caron and Shipshaw Projects. One-third of the total fall below Lake St. John was developed in 1925 by the Ile Maligne

hydro-electric plant operating under a head varying from 90 feet at maximum flood to 119.5 feet at low tail water and full reservoir in the lake. Development of the remaining fall of about 208 feet was

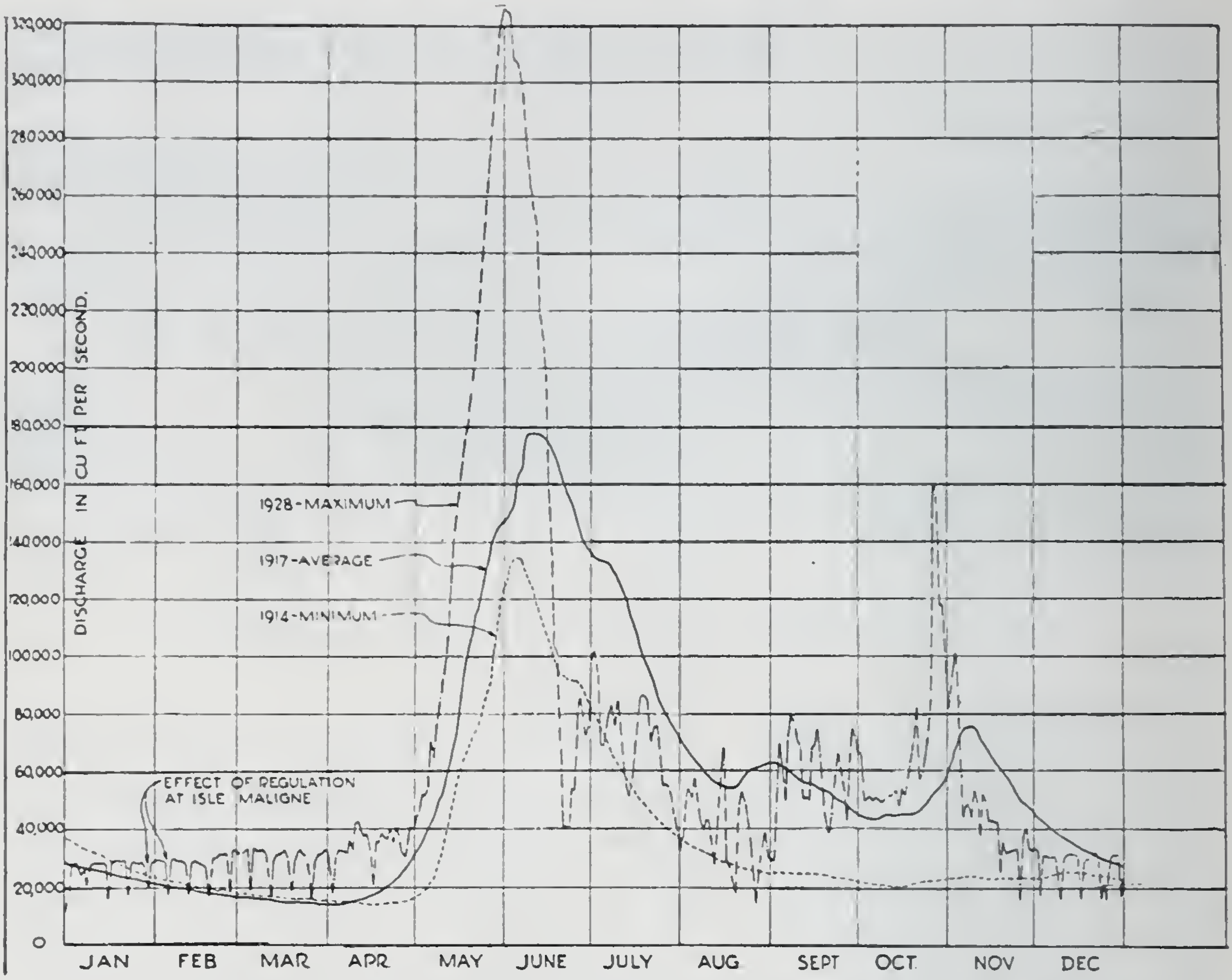

Fig. 3. Typical Hydrographs of Saguenay River at Chute à Caron.

planned originally in one stage with an ultimate power-house capacity of 1,000,000 horse power, developing more than 800,000 horse-power years of primary power.

On account of the magnitude of the undertaking, advantage was taken of the natural conditions at the site which permitted the development of a preliminary stage, known as the Chute à Caron project. As shown by Fig. 4, this project includes a massive gravity dam located above the rapids at Chute à Caron, together with the diversion works required for the construction of the main dam in the old river-bed and also includes a canal intake for the ultimate stage of development, known as the Shipshaw project. By the construction of a power-house at the intersection of the Chute à Caron diversion canal and the main dam, the available fall of 151 feet at that point

can be utilized with minimum initial expenditure and the demand for power met in the shortest practicable time. A total of 260,000 horsepower is being developed in this preliminary stage.

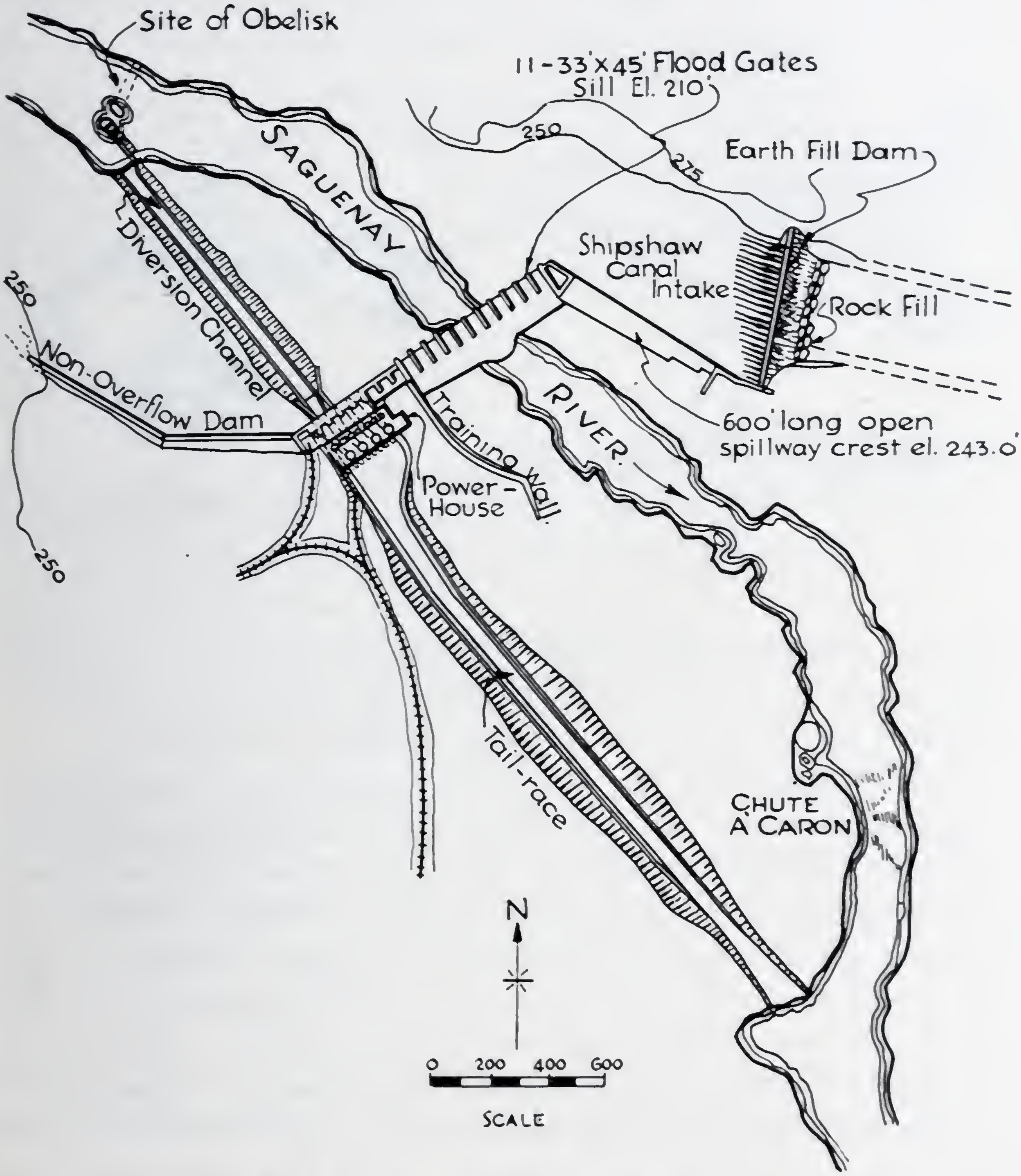

Fig. 4. General Plan of Development.

While this initial development is thus yielding a fair return on the big investment in the main dam, construction can proceed on the Shipshaw project—the ultimate development—in accordance with future power requirements. This latter work, requiring three years' additional time, will include the construction of three large earth

dams, a concrete combined spillway and forebay bulkhead at the lower end of the canal, and about 3,000,000 cubic yards of earth and rock excavation to form the power canal leading from the reservoir, above Chute à Caron dam to the Shipshaw power-house forebay. This canal will be located along the north bank of the river. (See

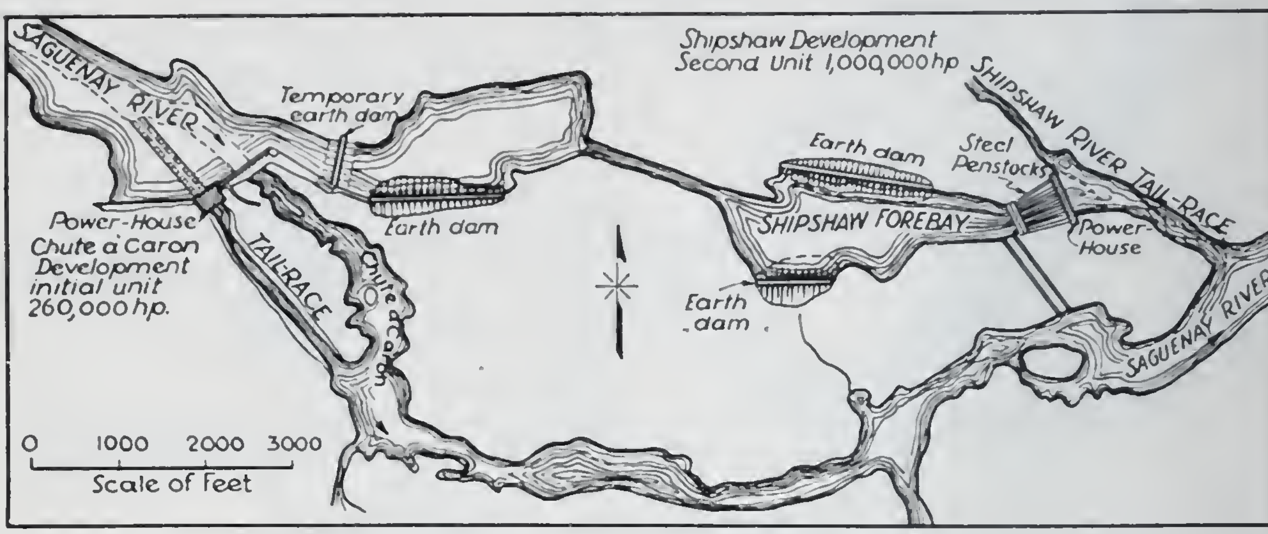

Fig. 5. Map of Shipshaw Development.

Fig. 5.) Shipshaw power-house will probably be built in several stages of two or three hundred thousand horse-power each and, when completed, will be one of the largest of its kind.

The Shipshaw tail-race will be an enlargement of the present Shipshaw River from the power-house site to its confluence with the Saguenay, a distance of about one-half mile. About 1,000,000 cubic yards of earth, gravel, boulders and rock will be excavated from this section of Shipshaw River to bring the tail-water elevation at the power-house to within a very few feet of tide-water level at Chicoutimi. To secure this further small increase in head would not be economically feasible, because it would be necessary to deepen some six miles of the Saguenay betwen the mouth of Shipshaw River and Chicoutimi.

When the Shipshaw project is ready for operation, the temporary earth dam now built across the canal intake at Chute à Caron dam will be removed and the Chute à Caron power-plant will thereafter be used as a stand-by, thus making spare units in Shipshaw power-house unnecessary, and, in effect, correspondingly reducing the cost of that power-house. During periods of excess flow in the Saguenay River the Chute à Caron plant will also deliver a large

block of secondary power for electric boilers and similar non-continuous service.

The Chute à Caron plant will contain four hydro-electric units of 65,000 horse power capacity each, under the normal head of 151 feet. The Shipshaw plant has been tentatively laid out for an ultimate capacity of 1,000,000 horse-power, as above stated, delivered either by ten 100,000-horse-power units or eleven 90,000-horse-power units under a net head of 205 feet. The ultimate projects on the Saguenay will thus create the following approximate water-levels (sea-level datum) under normal operation:

	Elevation	Gross head
Full reservoir, Lake St. John, corresponding to head-water at Ile Maligne	357.5	
Tail water at Ile Maligne	238.0	119.5
Head-water at Chute à Caron	238.0	
Tail water at Chute à Caron	87.0	151.0
Head-water at Shipshaw	238.0	
Tail water at Shipshaw (varies with tide), average	30 0	208.0

Preliminary Field Work. Preliminary work on the Chute à Caron project was begun in the summer of 1927 when a six-mile railroad spur was built to the site from Arvida, a station on the Canadian National Railway. Much of the construction machinery and equipment formerly used in constructing the Ile Maligne development was then delivered to the site and erection of the crushing and mixing plants was begun.

Camps. In the fall of 1927 housing facilities were provided for the construction staff and labor; these included four bunk houses for 400 laborers and two staff houses for the clerical help, survey parties, inspectors, and foremen. These buildings are of substantial construction (especially designed to withstand the winter temperatures, which reach 40 degrees below zero), and contain all essential modern conveniences of heating, ventilation, fire protection, and water-supply. Other buildings which make up the usual construction camp of this nature are an engineering and clerical office, a completely equipped testing laboratory for cement and concrete, a hospital and

dressing station, mess halls capable of feeding 1000 men, a storehouse, tool room, machine-shop, carpenter shop, and compressed-air plant, and a commissary carrying a full line of groceries, dry-goods, and clothing. (See Fig. 6.) For the superintendents and assistants

Fig. 6. Aërial View of Camp Site and Construction Plant.

in charge of construction, modern permanent homes were built, which will be occupied later by the operating staff after the project is completed.

Although a maximum of 1600 men was employed at the peak of construction in 1928, a larger camp for housing the laborers was not required because of the company's policy of employing principally native labor from the nearby towns of Jonquiere and Kenogami, only two miles away. Practically all of the labor is French-Canadian.

Sand Supply. The entire region in the vicinity of Chute à Caron is glaciated and contains numerous deposits of sand and gravel, most of which, however, were found to be of undesirable quality for

concrete, or too small to permit their economical use considering the size of the job. The necessary supply of sand was finally located by prospecting the region extensively. This was a difficult task because it was necessary to complete this work during the winter months, with a three-foot to five-foot blanket of snow on the ground, in order to be prepared sufficiently in advance of the first construction season. Several crews were sent out on snow-shoes, and a systematic exploration of various promising sand-pits was carried out within one to five miles of the dam site by digging holes into the deposits, some 20 to 30 feet deep, and estimating the approximate volume of suitable sand. Three months of exploration work located three areas of satisfactory sand, estimated to have a sufficient combined volume to meet the demands of the project.

Supply of Coarse Aggregate. The rock which was excavated in the areas of the diversion channel, tail-race, power-house and dam was used for the coarse aggregate, thus saving the expense of a quarry.

Crushing Plant. The coarse-aggregate plant consists of a series of crushers, screens and conveying equipment as shown diagrammatically in Fig. 7. The primary breaker is a 60- by 84-inch Allis-Chalmers jaw crusher driven by a 400-horse-power motor. This crusher can take a 60-inch rock and turn out a 14-inch product. The secondary breaker is a No. 15-N Allis-Chalmers gyratory crusher, driven by a 200-horse-power motor; the feed is 14 inches and the product six inches for Class A and Class C concrete. There are also four Allis-Chalmers 6-N gyratory crushers driven in pairs by 150-horse-power motors, which reduce the six-inch stone to three inches when required for Class B concrete.

Concrete. Since the construction work was carried on by the company's own forces it was not considered necessary to work under the usual detailed specifications for the concrete. The designing office merely specified three principal classes of concrete, as follows:

Class A concrete—Compressive strength, 3000 pounds per square inch at 28 days. Maximum size of coarse aggregate, six inches.

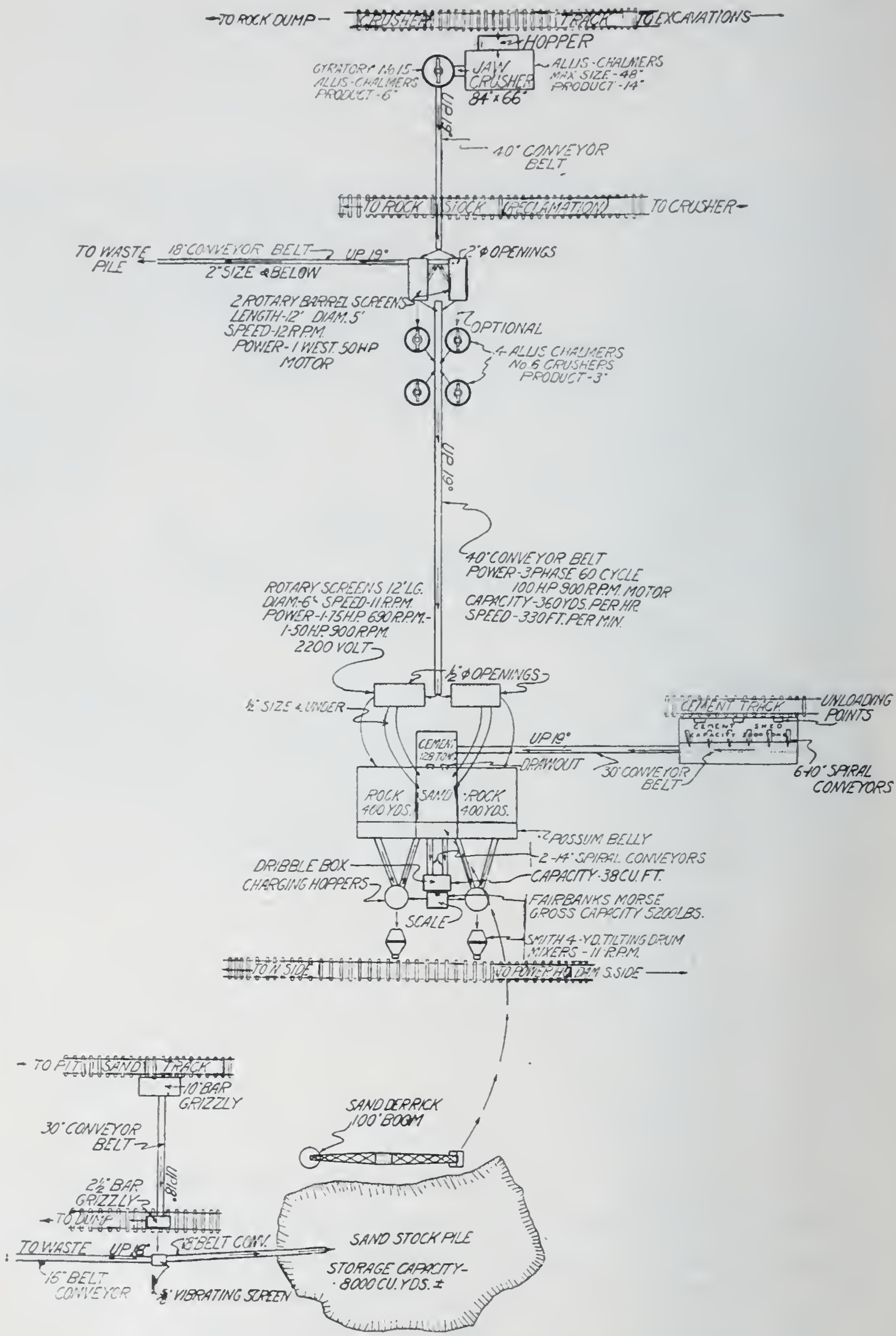

Fig. 7. Flow Diagram of Crushing and Mixing Plants.

Class B concrete—Compressive strength, 3000 pounds per square inch at 28 days. Maximum size of coarse aggregate, three inches.

Class C concrete—Compressive strength, 1500 pounds per square inch at 28 days. Maximum size of coarse aggregate, six inches.

The strengths designated are based on 6- by 12-inch laboratory test cylinders, with due allowance for the unusual size of the coarse aggregate as actually used in the mass concrete.

The matter of quality of aggregates, design of mixture, workability, placing methods, curing and winter protection, was left to the judgment of a concrete technician who not only had charge of the field laboratory, but exercised full supervision over the mixing and placing.

The compressive strength of 3000 pounds for Class A was specified principally to assure definite waterproof and weather-resisting qualities for the surface concrete in the dam; Class B concrete was used in the smaller structures and where reinforcing bars precluded the use of large aggregate; Class C concrete was used in the body of the dam where the stresses are relatively low and weight is the principal requirement.

The mixture design was based on the water-cement ratio law; that is, to a designated quantity of water and cement are added sand and stone in sufficient proportions to produce a workable mass. The workability was varied to suit the conditions of placing, under the strict control of the concrete technician, by manipulating the relative amounts of sand and stone rather than by changing the water and cement content. The concrete was unusually dry, practically without slump, and the strengths obtained were parallel to, but considerably above, Abram's curves.

The average mixes for the three classes of concrete were as follows:

Class	Water-cement ratio	Proportions — Cement	Sand	Rock	Pounds of cement per cubic yard of concrete
A	0.90	1	2.12	5.43	436
B	0.80	1	2.44	2.87	572
C	1.10	1	3.08	8.23	294

Grading of Coarse Aggregate. The product of the secondary breaker, above referred to, is passed through a pair of revolving screens having 2½-inch circular openings which remove and waste all material smaller than about two inches. The coarse aggregate, Class A and Class C concrete, is therefore graded from two to six inches. Numerous laboratory experiments and actual field tests have demonstrated conclusively that coarse aggregate of this gradation will produce better concrete for less money than a uniformly graded aggregate, for the following reasons:

1. A greater quantity of coarse aggregate can be added to a fixed amount of mortar than is possible with aggregate of "ideal" gradation, and still produce a workable mass. This is equivalent to a reduction of cement per cubic yard of content, which means cheaper concrete.

2. It was found that any coarse aggregate ideally graded from ½ inch to six inches shows a pronounced tendency toward segregation and grouping of sizes. Such segregation and grouping of sizes tends to harshen the mixture and interferes with its workability.

3. With the ideally graded coarse aggregate there is also a very noticeable separation of sizes, or raveling, in the storage bins and, unless such aggregate is separated into two or three sizes and then recombined in proper proportions at the mixer, this feature becomes quite troublesome and produces non-uniform concrete due to the wide variation in gradation from batch to batch. With the smaller sizes removed, the raveling is reduced to a minimum and the workability and quality of the concrete become more nearly uniform.

4. If the mortar content is increased until the mass of ideal gradation becomes workable, it amounts roughly to 125 per cent. of the voids in the coarse aggregate. In aggregate graded from two to six inches, a mortar content equal to about 110 per cent. of the voids in the stone will produce a workable concrete. (See the first item in the list of references at the end of this paper.)

Cement Storage. Adjacent to the mixer plant there was erected a series of bulk cement storage bins with sufficient capacity to receive daily shipments in excess of the amount required to meet the maximum concreting schedule of 3300 cubic yards per day of 24 hours. The shipments were planned to range from three to 10 cars a day.

An elevated track was constructed above the main storage bins where the cars are spotted and unloaded by manually operated mechanical scrapers; the actual unloading from cars to bins is being handled by contract at the fixed price of 11 cents a ton.

Mixing Plant. The mixing plant consists of two rock-storage bins, capacity 400 cubic yards each; one sand-storage bin, capacity 200 cubic yards; two water-storage tanks, capacity 5000 gallons each; two water-measuring tanks, capacity 30 cubic feet each; a cement-weighing device, and two four-yard Smith mixers. The mixers have special nickel-steel linings and baffle-plates to withstand the action of the unusually large coarse aggregate.

Precautions Against Fire in Crusher and Mixer Plants. The crusher and mixer plants may be called the heart of any big construction job and on this project it was of the utmost importance that reliability of operation be assured at all times, particularly during the low-water stage of the river. At this season temperatures are to be expected as low as 30 degrees below zero, Fahrenheit, and, while the main dam is being closed, large quantities of concrete must be placed in locations that would be difficult even under favorable weather conditions. Failure to meet strict construction schedules might mean a year's delay in the completion of the work; that is, work would stop for eight months until the next winter's low river stage occurs. In other words, the river flow conditions are such that the dam *must* be closed between December and the following March. Every precaution was taken, therefore, to prevent fires in the plant. Steel beams were used for all principal structural members, corrugated iron sheathing was employed wherever possible, special fire doors were placed to prevent fire drafts through long conveyor passageways, all woodwork was painted with a special mixture of fish-glue and cement and an ample sprinkler system was installed. The glue and cement mixture has excellent characteristics as a non-inflammable paint and keeps the wood from igniting from sparks or small fires. The sprinkler system, of special design providing extra large water capacity to all important sections of the plants, consists of separate pipes, all running from a common header in the sprinkler valve house, where the supply of water to any particular section of the crushing and mixing plants can be controlled manually.

Other Construction-Plant Buildings and Equipment. The machine-shop and the blacksmith shop are fully equipped with modern machinery, such as lathes, drills, shaper, pipe-cutter and threader, shears, forges and a power-driven forge-hammer, so that practically all repair and replacement parts required for the construction equipment as well as many other articles, can be fabricated on the job.

The carpenter shop is similarly equipped with power-driven machinery, including band-saws, rotary saws and planers for the fabrication of the complicated form work required in the construction of the draft tubes, intake transitions and similar structures.

The extensive rock-drilling operations over the entire site of the work required the laying of a suitable piping system to distribute compressed air from a battery of air-compressors, which have a total capacity of over 6000 cubic feet of free air per minute and are connected to after coolers for removing the condensate, thus preventing freezing of the lines in winter.

A Gilman drill-sharpening plant, containing automatically controlled furnaces, tempering machines and a drill sharpener, assures a constant supply of new drill steel of highest quality, with a longer life and more uniform wear than had ever been obtained from manually sharpened drills on the company's drilling work elsewhere.

Electric Power for Construction Plant. Electric drives are used wherever possible on all derrick hoists, travelers and shop equipment, as well as in the crushing and mixing plant, not merely to reduce the fire hazard, but principally because of the greater economy in this region of comparatively cheap hydro-electric power. Energy is purchased from one of the smaller hydro-electric plants of Price Brothers & Company, Ltd., only a short distance from the Chute à Caron site. The entire camp is suitably electrified through a central substation and a general distribution system.

General Features of Development. Fig. 4 shows a general plan of the entire development. Beginning at the extreme end on the right bank of the river looking down-stream, a non-overflow section of gravity type dam (See Fig. 8) extends 1100 feet to the power-house where there is an erection bay for the handling, in assembled form, of flood-gates from the railroad track to the top of the dam. The power-

house structure forms an integral part of the dam and next a non-overflow gravity section is carried 150 feet to join the main spillway. This spillway has a total length of 495 feet and is of ogee section, as shown in Fig. 9. The 11 flood-gates in this section provide for a normal flood discharge of 340,000 second feet. This spillway extends as far as the inlet for the canal leading to the Shipshaw power-house. At this point the dam parallels the line of the canal and is a free

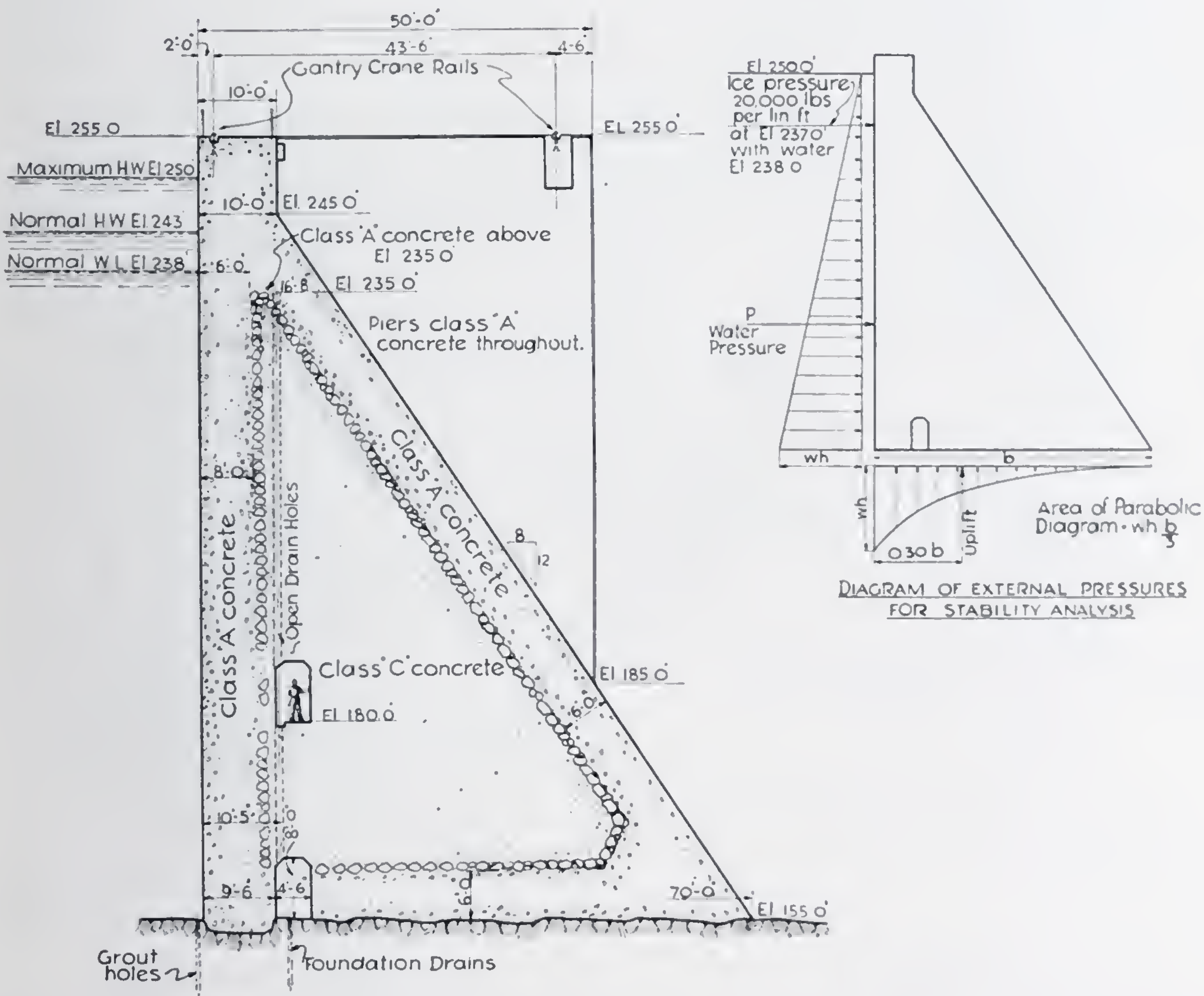

Fig. 8. Cross-Section through Bulkhead Section of Main Dam.

overflow spillway 600 feet long with its crest at an elevation of 243 feet, level with the top of the flood-gates. This free spillway crest is provided for additional flood discharge due to a possible rise in the reservoir to an elevation of 248 feet. Under this condition a flood of 455,000 second feet can be passed through the flood-gates and over the free spillway crest. The extreme maximum flood that can be discharged safely is in excess of 600,000 second feet—a condition that in all probability will never occur.

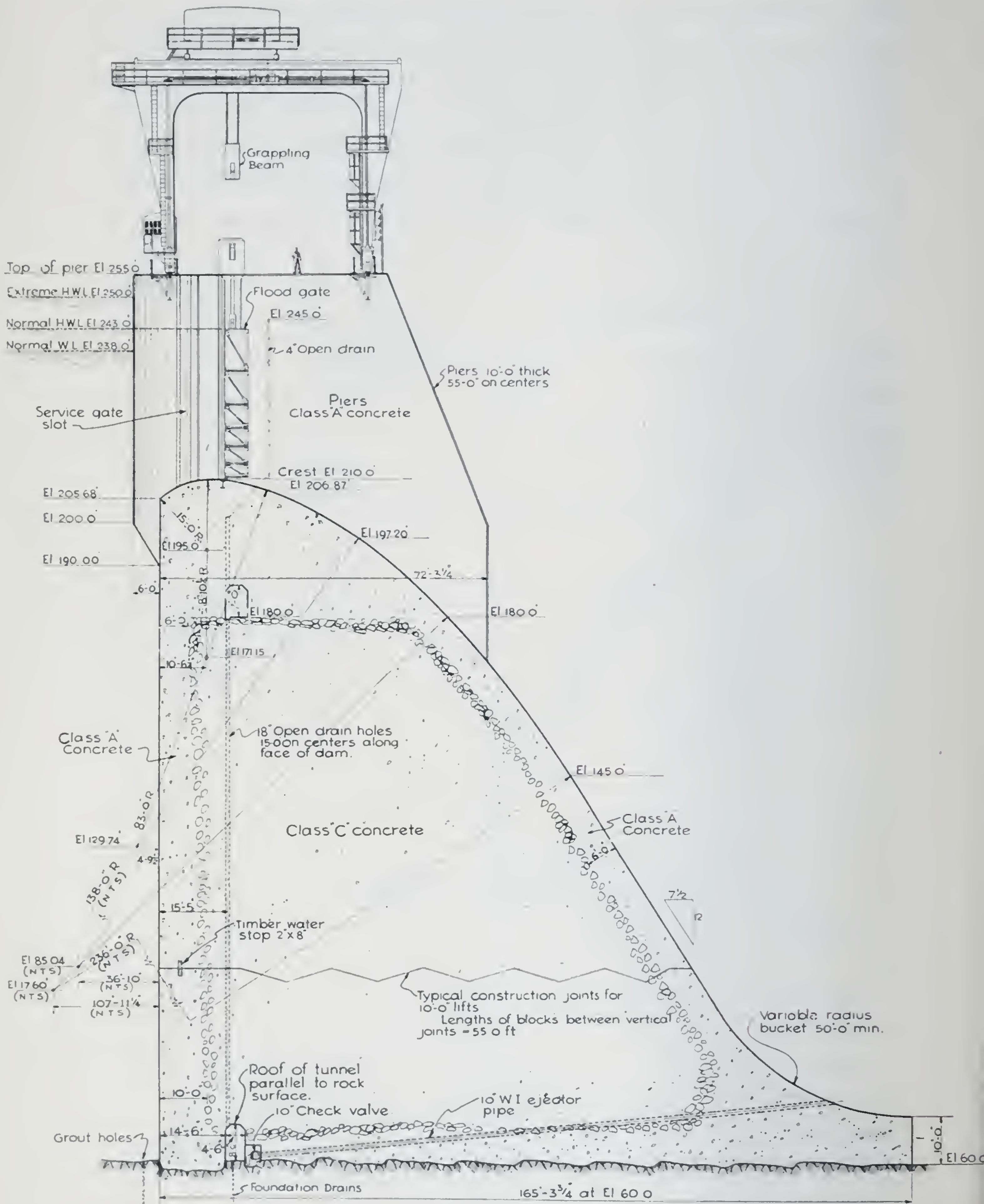

Fig. 9. Main Spillway Section of Dam.

Design of Gravity Dam. In the design of the gravity sections of the dam, extensive provisions were made to prevent seepage and uplift. A series of vertical open drains, 18 inches in diameter, is located 15 feet, 5 inches from the up-stream face of the dam at 15-foot intervals along its entire length to accumulate any seepage which may penetrate into the concrete. In addition, special vertical sealing strips and drains are provided at all vertical construction joints, while the horizontal joints have seepage cut-offs near the up-stream face consisting of two-inch by eight-inch rough wooden planks half embedded edgewise in the concrete at the top of each lift. Upon pouring the succeeding lift, the upper half of this wooden cut-off is completely embedded in concrete. Any water that reaches this cut-off causes the wood to swell and make a water-tight seal. This type of cut-off was, so far as the writer knows, first used on Calderwood dam, where it was found to be entirely satisfactory.

There are two inspection galleries—one, located near the top of the dam, provides for inspection and the cleaning of the vertical drains; the other, located directly on the rock foundation, serves to cut off any seepage along the joint with the ledge and also receives all the seepage accumulated by these vertical drains. The lower inspection gallery is drained by ejector pipes leading to the bucket of the dam, where suction created by the sheet of spilling water will remove any water that may collect.

To prevent seepage along fissures in the ledge under the dam, a continuous series of grout holes, about 30 to 100 feet deep and 10 feet from center to center, was drilled near the up-stream side of the lower inspection gallery and grouted under high pressure.

In spite of these precautions, the dam was designed with an assumption of full head uplift at the face, decreasing parabolically to zero at the down-stream toe as though all of the drainage provisions heretofore described were plugged or entirely lacking. This assumption of uplift was also applied at all horizontal construction joints above the foundation.

In order to confine to the main river channel any water spilled over the dam at its south end, a long concrete training wall was built between the tail-race and the river channel. This wall was designed on the basis of tests made upon a model built in the hydraulic laboratory of the Carnegie Institute of Technology, Pittsburgh. (See Fig. 10.) This model was constructed on a scale of 1 to 100.

Shipshaw Canal Inlet and Earth Dam. The construction of the inlet to the future Shipshaw power canal was undertaken at this time in order to avoid the under-water excavation of large quantities of rock, which excavation would have been required had the work been postponed until the Chute à Caron plant was in operation. The inlet was excavated to its ultimate width of 400 feet and closed by an earth dam, 55 feet high, consisting of a puddled clay core with sand fills on each side, backed with heavy riprap on the up-stream face and a rock fill at the down-stream toe. By this expedient it will be possible, after the Shipshaw canal is completed, to remove the loose material forming the earth dam, initially on the dry side with a steam-shovel and later with an excavator or similar equipment capable of operating under water, and thus connect the power canal with the reservoir above the dam.

Fig. 10. Hydraulic Model of Spillway over Chute à Caron Dam.
Scale 1 to 100.

Flood-Gates. The Stoney-type flood gates, 11 in number, are 33 feet wide and 45 feet long, and each gate weighs 80 tons. They are controlled by two 115-ton gantry cranes of special design containing overhead traveling trolleys and also an automatic handling and dogging system which permits a single operator to maneuver quickly

and to latch each gate at any one of five different openings. There is also an emergency or service gate, which can be placed in front of any flood-gate for removing and repairing the gate without undue waste of water. The gantry cranes travel on steel girder runways with a walkway extending from the top flange on the up-stream side of each girder. These girders are spaced 43 feet, 6 inches from center to center, the same spacing required for the derrick travelers used during construction of the dam. The gantry also provides service at the intake in handling the intake gates and sectional racks, and permits the raising of flood-gates from flat-cars located on the ground below the dam.

Ice. Special precautions were taken to prevent ice from interfering with the operation of the flood-gates. An air-bubbling system has been provided along the up-stream faces of these gates in accordance with more or less standardized practice. Electric heaters are placed in the gate slots along the sealing faces and behind the roller trains supporting these gates.

Power-House. The general cross-section of the power-house is shown in Fig. 11. The intake is a massive reinforced concrete struc-

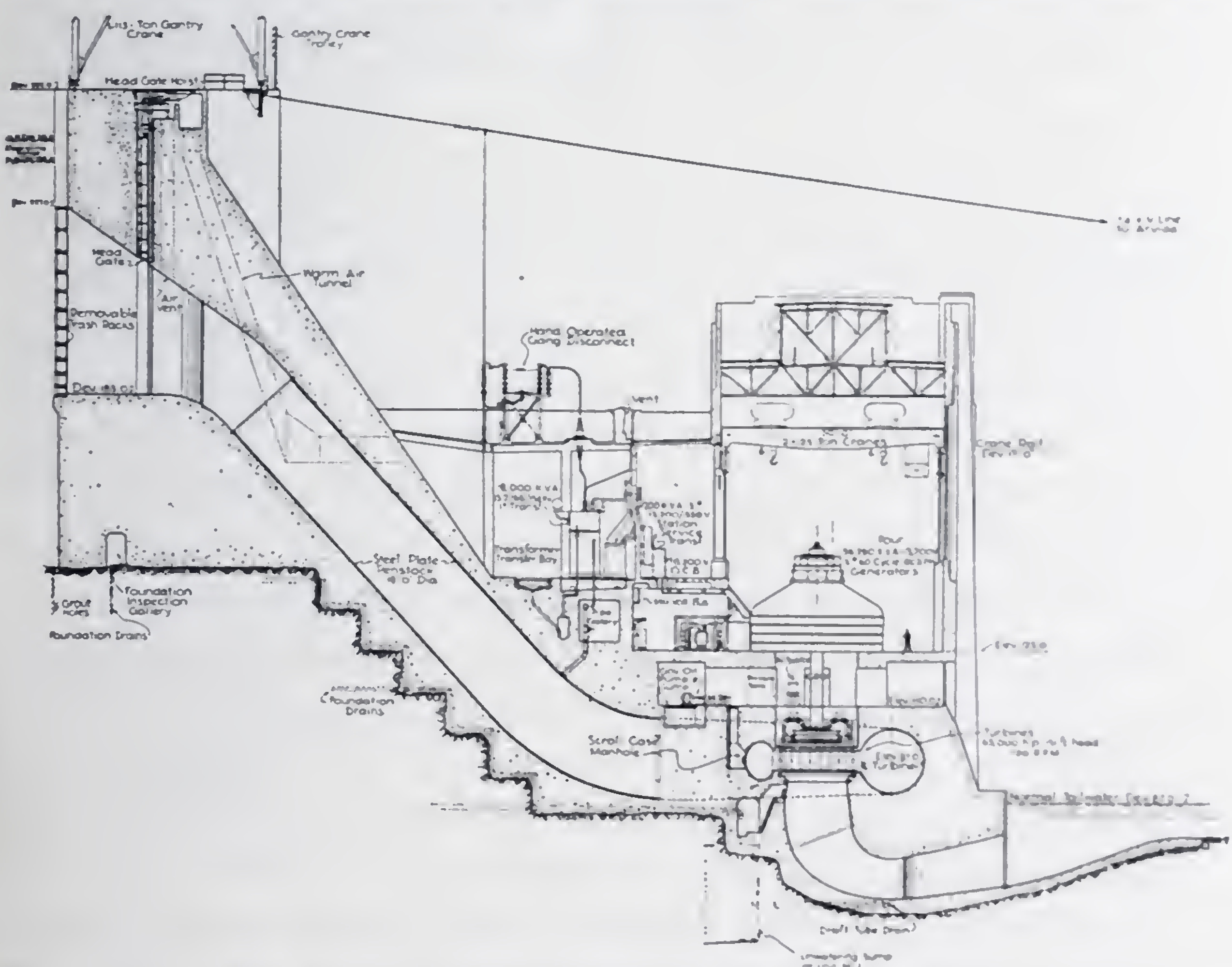

Fig. 11. General Cross-Section of Power-House.

ture designed to be stable in itself as a gravity section. The racks in front of the inlets to the turbines are located well below normal elevation of the reservoir level and also below the ice sheet in winter. Since the reservoir will be covered by a continuous ice sheet from Chute à Caron dam to Ile Maligne tail-race there will be no interruption of service by frazil.

The trash racks are electrically welded. They consist of 7/16-inch by 5-inch steel bars, with rounded up-stream edges, spaced 4½ inches apart. They are built in sections, which are removable to facilitate painting and repairs. The strength of these racks is sufficient to withstand the full head of water, under stresses near the elastic limit, thus permitting a sheet-steel curtain to be lowered over the racks for the purpose of unwatering the intake in front of the head-gates should the necessity arise.

Each turbine intake has two fixed-roller-type head-gates, operated by individual electric hoists normally controlled from the hoist chamber just below the intake deck; the gates can also be lowered by pressing a button in the control room. Closing from the control room may be effected without electrical power on the motor hoists, the gates being permitted to fall under their own weight with special provision against their gaining excessive speed. This represents a new departure in design of gate hoists and consists essentially of a rotary fan, coupled directly to the motor shaft, which will absorb a large amount of energy when driven in the reverse direction by the descending gate. Energy developed by the falling gate is thus absorbed by the fan and by friction in the gear system of the hoist. The gate hoists are protected from the weather by their location in closed chambers below the intake deck. In winter, warm air is brought to these chambers by air-ducts leading from the generator room. Through hatchways in the deck over these chambers, the gates and hoists can be readily serviced by the traveling gantry cranes.

Each intake entrance is of bell-mouth construction, and consists of two openings 20 feet wide by 44 feet high, separated by a short intermediate pier, converging into a circle 19 feet in diameter, from which section the water is carried to the scroll case by a steel-plate penstock incased in concrete and designed for full head.

The substructure is of massive reinforced concrete construction throughout and contains elbow-type draft tubes of the S. Morgan

Smith Company's design. At the down-stream end of each draft tube provision is made for placing needle-beams in case it is desired to unwater the draft tube for inspection or repairs. Each draft tube is provided with a special drain-pipe leading to a common sump from which the water may be pumped into the tail-race.

The cooling air for the generators enters through windows in the turbine room, passing thence through openings in the generator supporting pier to the underside of the generators.

The oil-storage tanks are located at the south end of the power-house immediately under the railroad track. Below the oil-tanks are located a filter and purifier with suitable pipe headers. A pipe distribution system runs from this point to the various oil-tanks and to the transformers, oil switches, governors, sump tanks, etc.

Above the generator floor level is a structural steel framework supporting the roof and crane runway. The roof includes a full-length monitor with motor-operated sash to allow the passage of excess hot air from generators to the outside. The power-house is a reinforced concrete structure with bold architectural treatment.

Between the intake and main superstructure are located the various cells and rooms for low- and high-tension electrical equipment, station service equipment, and the control room, office, and store-room.

Machinery and Equipment. The four turbines were designed by the S. Morgan Smith Company and built in Canada by its affiliated company, the S. Morgan Smith-Inglis Company, Ltd. They are rated at 65,000-horse-power each under a head of 151 feet and 120 r.p.m. Each runner is a single-cored steel casting, 95,000 pounds in weight and with a maximum diameter of 13 feet.

The scroll cases are of heavy steel-plate construction varying from 1¼ inches maximum to ¾ inch minimum thickness with an inlet diameter of 17 feet, 6 inches. They are completely incased in concrete, the top of this covering forming the turbine-room floor on which are located the governors, oil pumps and pressure oil-tanks.

The governors have Woodward actuators, with the fly balls electrically driven by induction-motors. Each motor receives its 155-volt, eight-cycle, three-phase energy from slip-rings on the pilot exciter, which is mounted on the main shaft of its respective unit, sur-

mounting the main exciter. This system of governor drive, a distinct improvement recently introduced by the Aluminum Company of America on its hydro-electric units, removes the objections to electrical drive from the generator terminals and is another step beyond the earlier mechanical drives.

The generators are of Canadian Westinghouse manufacture, rated at 56,250 kilovolt-amperes, 13,200 volts, three phase, 60 cycles, 120 r.p.m., and include both main and pilot exciters. The latter serves a dual purpose. It delivers a constant voltage for the main exciter field circuit, thus providing good excitation stability and high speed of voltage regulator response, and in addition it provides eight-cycle power for driving the actuator fly balls.

Arrangement of Electrical Equipment and Auxiliaries. A one-line diagram of the main connections of Chute à Caron power-house is shown in Fig. 12. The usual generator bus at the power-house is

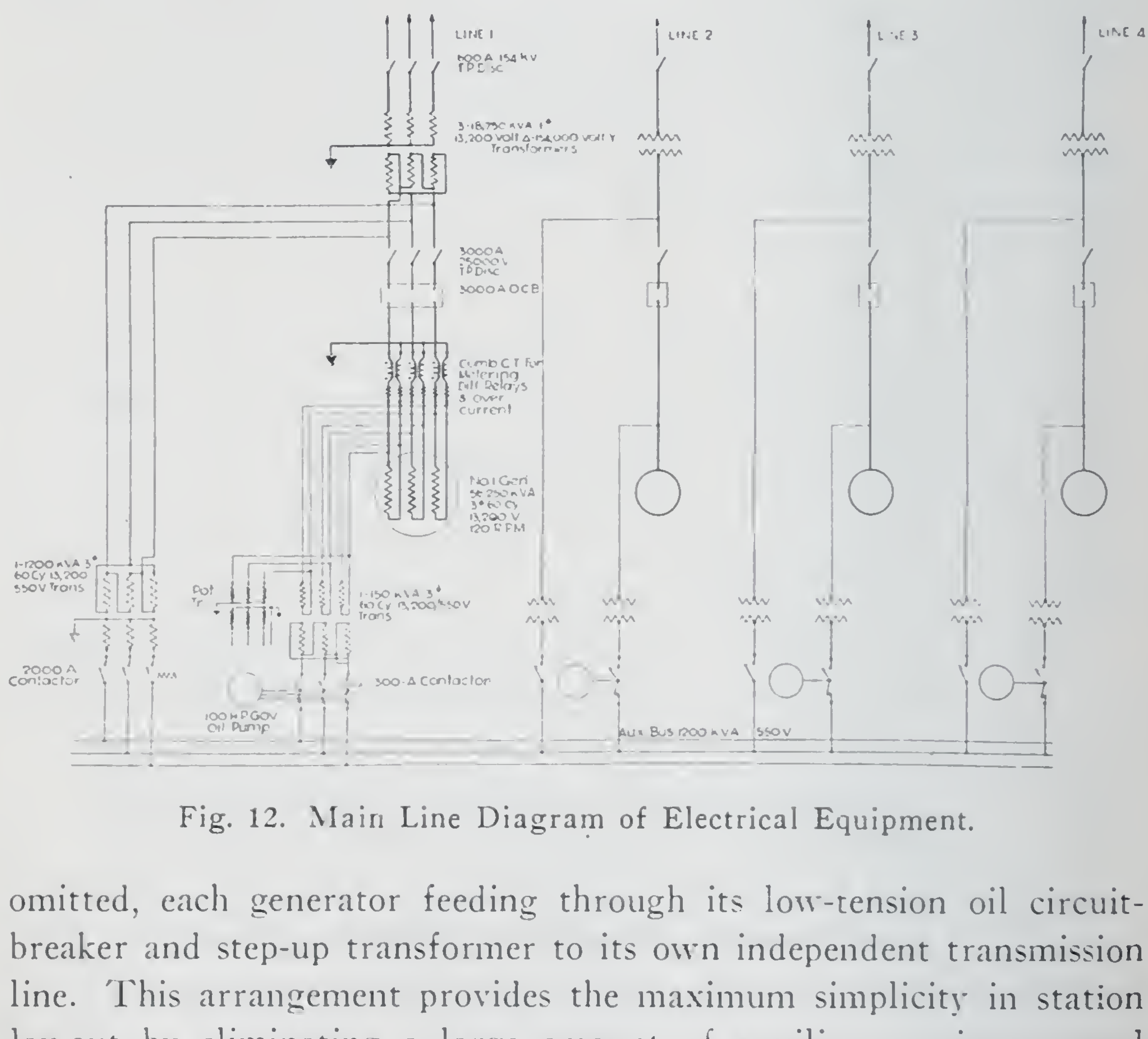

Fig. 12. Main Line Diagram of Electrical Equipment.

omitted, each generator feeding through its low-tension oil circuit-breaker and step-up transformer to its own independent transmission line. This arrangement provides the maximum simplicity in station lay-out by eliminating a large amount of auxiliary equipment and

connecting buses, thereby reducing operating problems to a minimum. The choice of this simple system was made possible by the length of the transmission line which extends a distance of only four miles to the substation at the Arvida aluminum plant; the necessary transfer and distribution of load is handled entirely at this substation. The transmission line consists of two double-circuit tower lines carrying steel-reinforced, aluminum cable of 447,000 circular mils.

The extensive use of electrical heaters on the flood-gates, already described, together with the auxiliary equipment in the plant, causes a rather large station service load, amounting to approximately 1000 kilowatts. Since no generator bus is available to supply an auxiliary transformer bank, four 1200-kilovolt-ampere transformers are supplied, one for each generator, the high-tension side of each being connected directly and without protection to the low-tension terminals of the main transformers of its respective bank. (See Fig. 12.) Only one of these auxiliary transformers can be in service at any time, an automatic selector being provided to connect the 550-volt station bus to any one of these transformers. This selector consists of a motor-driven drum which provides the necessary interlocking between the auxiliary contactors, and, if for any cause the auxiliary bus becomes de-energized, the drum will advance progressively to the next contactor in sequence until it connects with an energized station service transformer to re-energize the bus.

The 550-volt auxiliary system is provided with a grounded neutral to make sure that any load is promptly disconnected in the event of a ground.

The governor pumps constitute the most important unit auxiliary. Each of the four pumps is driven by a 100-horse-power squirrel-cage motor. The normal feed for each governor-pump motor is from its own generator terminals through a 150-kilovolt-ampere transformer. This overrating of transformers was selected to insure their operation at such low temperatures as to require no special provisions for cooling and ventilating. If at any time this power source should fail, the governor-pump motor is automatically transferred to the station auxiliary bus. In effect, this gives each governor pump five sources of power, the normal feed being from its own generator terminals. The small governor-pump transformer is connected, as shown in Fig. 12, inside of the differential protection of its generator, so that it is pro-

tected by the double primary differential current transformers to the same extent as the generator.

The generator oil circuit-breakers are General Electric type, FH-209-B, rated at 15,000 volts, 3000 amperes, and 1,500,000 kilovolt-amperes rupturing capacity.

The 13 main transformers—one being a spare—were built by Hackbridge Electric Construction Company, Limited, of England. They are of the water-cooled, outdoor type, equipped with conservators. Their normal rating is 18,750 kilovolt-amperes, single phase, 60 cycles, at 50 degrees C. rise, 13,200 volts delta to 154,000 volts star. They are insulated for use on a 154-kilovolt non-grounded system.

It was extremely desirable to be able to supply some of the Chute à Caron power at a nominal voltage of 66 kilovolts. For this reason each transformer has its high-tension 89,000-volt winding divided into two groups which can be connected either in series or in parallel by means of tap changers. In addition, each half of the high-tension winding is equipped with two five per cent. taps below normal. This permits their full-capacity operation at 69 kilovolts, using the transformers star connected with the high-tension windings in parallel and the 90 per cent. tap in service.

The control power is furnished by a 60-cell, 400-ampere-hour "exide" sealed jar-type battery. This battery is continuously floated across the terminals of a 7.5-kilowatt, 140-volt diverter pole motor-generator set, driven from the 550-volt station bus. It can also be charged, when desired, from the 350-kilowatt motor-generator set, which normally serves as a spare exciter.

The switchboard, manufactured by the Canadian General Electric Company, Ltd., consists of a unit combining both the vertical panels and an operator's bench-board. It is U-shaped, with the bench sections extending from two of the vertical panels. It includes all of the meters and relays for the main generators and switches, as well as part of the special selector equipment used to control the power supply to the 550-volt station auxiliary bus.

The voltage regulators are of the exciter rheostatic type, manufactured by the Canadian Westinghouse Company. The regulator panels form part of the main switchboard adjacent to the bench sections. The main exciter shunt fields are divided into two circuits, the

regulator rheostat being of twin construction. This design, combined with the use of the pilot exciter, provides a reasonably quick response.

The 550-volt, 1200-kilovolt-ampere station auxiliary bus is made of "channeluminum" conductors. Each phase consists of two four-inch aluminum channels arranged face to face; or, in other words, the equivalent of a four-inch square aluminum tube, split vertically into two sections. In this manner full ventilation on all surfaces is obtained, skin effect is practically eliminated, and the mechanical strength of this design permits a reduction in the number of insulator supports as compared with ordinary bar construction.

The main leads between the generator and the oil circuit-breaker, as well as from the oil circuit-breakers to the transformers, are of a similar construction, each phase consisting of two five-inch aluminum channels arranged as above described.

Miscellaneous Station Equipment. The auxiliary station equipment includes the following:

Two Dominion Bridge Company power-house cranes, each of 125 tons capacity, with 25-ton auxiliary hoists, operating at 250 volts direct current.

One spare exciter, consisting of a 350-kilowatt motor-generator set, which also supplies direct current to the power-house cranes.

General public address system throughout the station.

Elevator running from the power-house to the top of the dam.

Complete water-supply, including chlorinating equipment for sterilizing the Saguenay River water and delivering it to the drinking fountains in the power-house and to the operators' homes.

Complete oil system, consisting of tank storage, central pump, and "hydroil" purifier.

The heating of the station is done primarily by circulation of the hot air from the generators, and secondarily by electric space heaters in the smaller rooms.

Construction Methods. The dam crosses the Saguenay at a narrow gorge where even in time of lowest flow the water was 65 feet deep; hence one of the chief problems in connection with the building of the dam was control of the river during construction. To accomplish this, a complete diversion of the river through an artificial channel or by-pass presented the only feasible solution. Because of

the large quantities of earth and rock excavation involved in the construction of this channel, amounting to some 700,000 cubic yards of loose material and 500,000 cubic yards of solid rock, initial operations were concentrated on the channel in the fall of 1927. The excavating equipment consisted of two 2½-yard railroad-type steam-shovels, one 1¾-yard Bucyrus 50-B electric crawler-type shovel, and one 1½-yard and one one-yard crawler-type steam-shovel. Most of the above equipment was brought from the Ile Maligne job. Later, a four-yard Bucyrus 120-B electric crawler-type shovel was added and was capable of far greater production than all of the other shovels combined. A 12-mile system of trackage covered the entire job. The rolling-stock used on the excavation consisted principally of 22 steam locomotives of 40 tons each, and 60 dump-cars with a capacity of 20 cubic yards each.

The drilling for the rock excavation was done mostly by Canadian Ingersoll-Rand heavy sinker and drifter type drills; a total of 47 drills was used and 2000 to 2600 lineal feet of 1½-inch to 2½-inch holes were drilled each day. The excavation had been scheduled on a basis of 70,000 cubic yards a month, mostly solid or slightly fissured anorthosite (a hard, coarsely granular, igneous rock, somewhat resembling granite), but at the peak 120,000 cubic yards were excavated in one month. The excavated rock was stored near the crushing plant, from which it was reclaimed later and crushed into coarse aggregate for the concrete.

Before the 1928 spring flood arrived most of the upper end of the diversion channel had been excavated and a temporary coffer-dam built across its upper end to permit the continuation of down-stream operations during the period of high water in 1928. Excavation in the diversion channel and tail-race was completed in 1929. At the same time, excavation for the dam foundations was continued on both sides of the river.

In the down-stream end of the diversion channel the top of the ledge is below the surface of the water when 50,000 second feet are discharged through that channel and, since the overburden is sand, it was necessary to provide a concrete lining in order to prevent erosion. The support for this lining consisted of reinforced concrete toe walls and, at intervals of 20 feet, a series of sloping concrete buttresses, cast in place. The lining proper was made of precast reinforced concrete

slabs, 19 feet 11 inches long, eight feet wide and one foot thick, weighing 12 tons each, placed upon and anchored to the buttresses, thus providing a trapezoidal channel with natural rock bottom and sloping concrete sides. The slabs were originally lashed to the supporting buttresses with ¾-inch old steel cables, but inability to draw the cables tight enough to prevent incipient vibration, due to the high velocity of the flowing water, made it necessary, after a few days' operation, to anchor the slabs to the buttresses with 1½-inch fox-bolts, thus providing a very rigid attachment. With this additional anchorage, the lining has been entirely satisfactory. Its general fea-

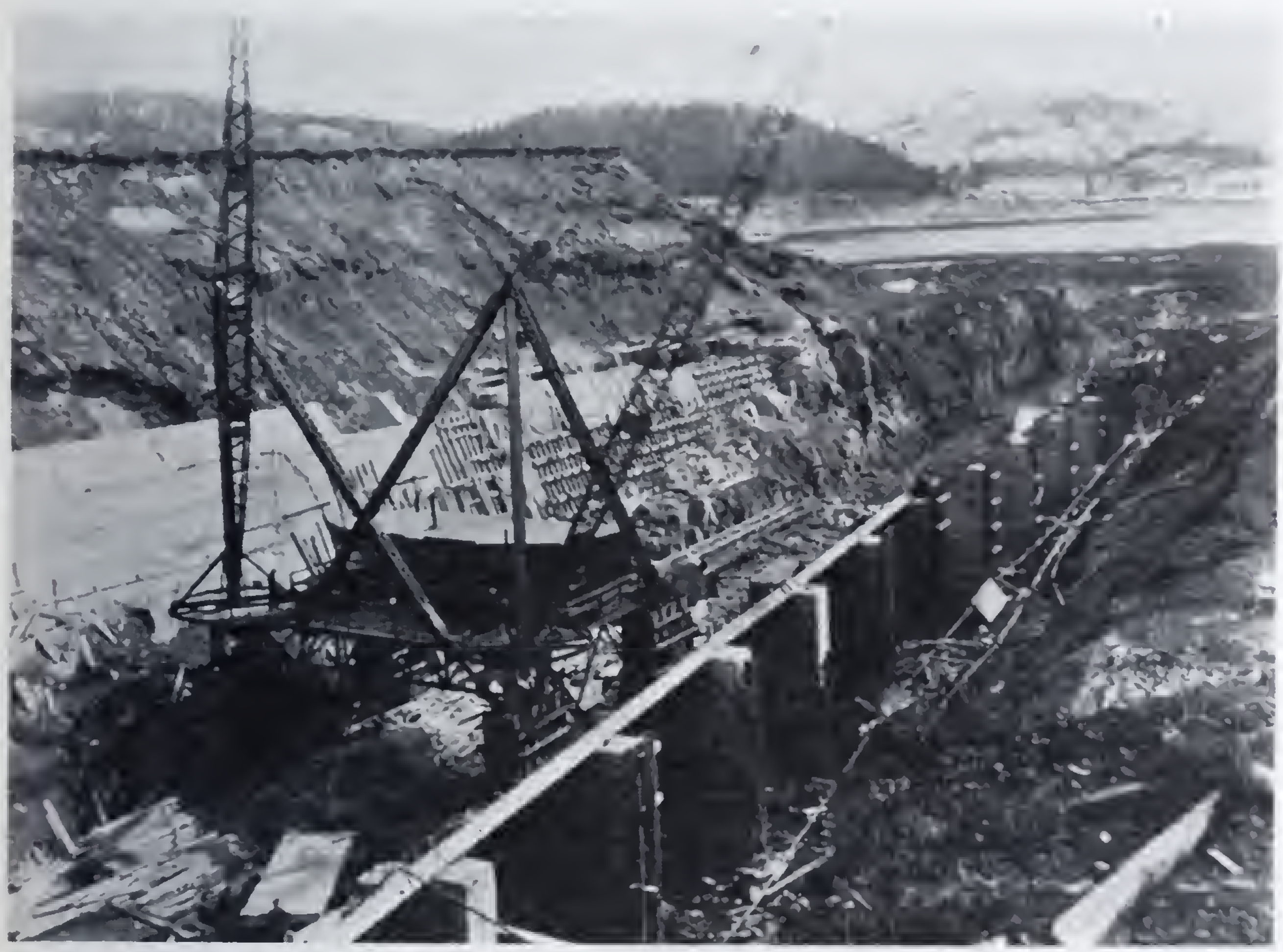

Fig. 13. Lining Tail-Race with Precast Concrete Slabs above the Rock Line to Protect Banks During Diversion Period (Looking Down-Stream).

tures are indicated in Fig. 13. The slabs were not designed to withstand hydrostatic pressure against their faces, as two-inch openings between their longitudinal edges permit slack water to collect behind the lining, thus equalizing the pressure of the water on both sides of the slabs.

When the plant is put in operation, the diversion channel below the power-house will serve as the tail-race.

Diversion Sluice Tubes Through Power-House. Down-stream from the power-house, the tail-race section of the diversion channel was designed with such bottom elevation as will develop economically the available head at the site, assuming normal water-level in the river at the point where the diversion channel joins it. Its general size and width were determined on the basis of a diversion of at least 40,000 second feet. This amount of water also had an indirect influence in determining the bottom elevation because the high current velocities during diversion periods made it advisable to keep most of this section in a rock cut.

Up-stream from the power-house, the fundamental principle in designing the diversion channel was to make it deep enough to carry economically a maximum flow of 50,000 second feet. Thus it is seen that the bottom elevations of the diversion channel, down-stream and up-stream from the power-house, were calculated to meet dissimilar requirements and, as a result, the bottoms of the two sections have a difference of 42 feet in elevation where the diversion channel passes the dam through the power-house. This offset in levels required the construction of a connecting concrete sluice tube, and the most economical location was obviously directly through the power-house, which in reality is a part of the dam. (See Fig. 14.) By means of extensive experiments on a model built to a scale of 1 to 18 (See Fig. 15) it was determined that twin sluice tubes, located along the center-line of No. 1 draft tube, would safely carry a maximum discharge of 50,000 second feet. Furthermore, that by lining the bottom of the tail-race for a distance of 300 feet below the power-house, no destructive erosion would develop. Fig. 16 shows the location of the sluice tubes with respect to the intake and power-house structure, the section being taken on the center-line. Discharge through the tubes is controlled at their upper ends by two 65-ton Stoney gates, each 20 feet wide by 40 feet high. After the main dam is completed these gates will be lowered to "close" the dam and impound water in the reservoir. The sluice tubes will then be filled with concrete, and the omitted portion of the substructure for unit No. 1 will be constructed.

Up-Stream End of Diversion Channel. Above the point where the diversion channel leaves the main river there are at times of low water two small rocky islands on the south side of the main channel.

Fig. 14. Looking Up-Stream at Excavated Site of Power-House and First Stage of Sluice Tube Construction.

Fig. 15. Model for Predetermining Performance of Sluice Tubes. Scale 1 to 18.

These were connected to the south bank by rock-filled crib coffer-dams, one extending across the inlet to the diversion channel, the other running parallel to that channel to form a barrier between it and the river along the low portions of the river bank. These two coffer-dams closed off the upper end of the diversion channel for its final excavation. After this work was completed the coffer-dam across the inlet was removed, thus preparing this channel for final diversion

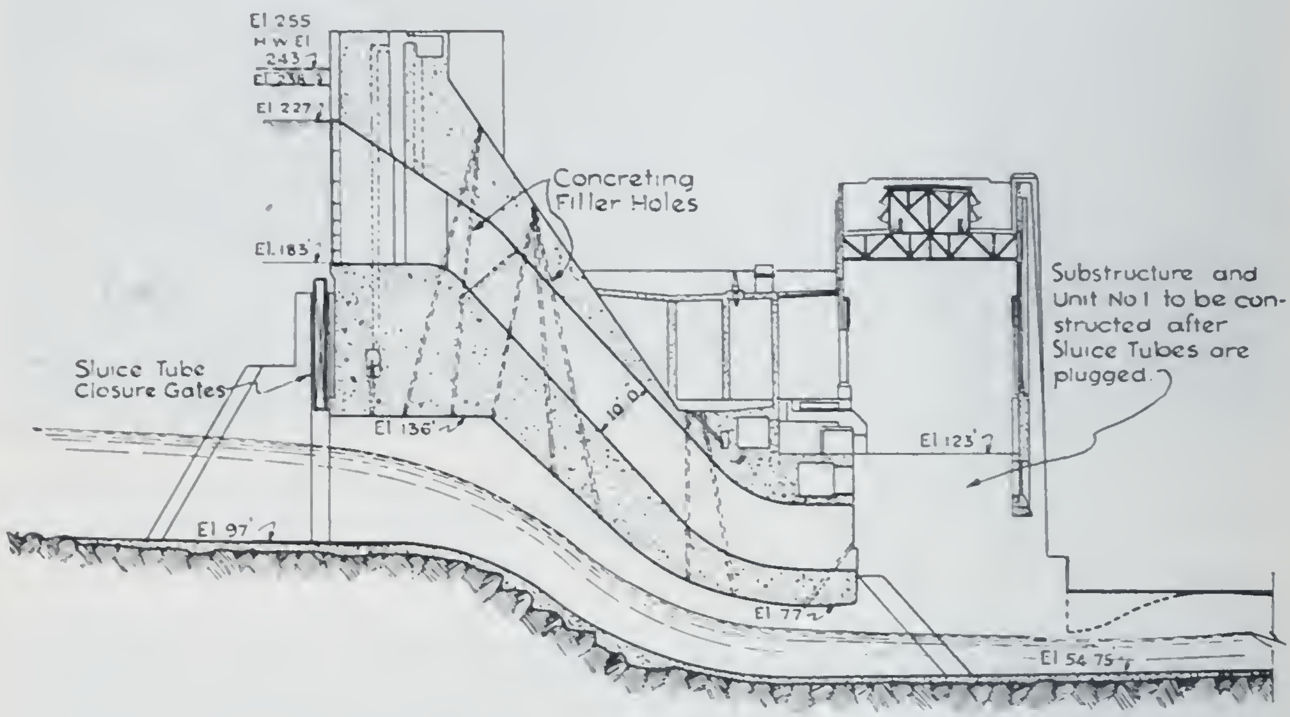

Fig. 16. Section through Diversion Sluice Tubes and Power-House at Unit No. 1.

of the Saguenay, to allow the completion of the dam across the gap (200 feet wide, 65 feet deep at low water) in the old river-bed.

While this work was going on, a large reinforced concrete mass, for convenience termed an "obelisk," was built on the mid-channel island. Special provisions were made in its pedestal to allow the blasting away of one of the supports; this would cause the obelisk to tip into and block the main channel, thus diverting the entire flow, up to 50,000 second feet, into the now completed diversion channel and permitting construction to proceed on the main dam in the old river-bed. This scheme was developed by the writer, and careful study proved it to be the only feasible method of diverting the river under the existing conditions of high velocities in a deep channel with flood discharges that, according to past records, might be as much as 175,000 second feet.

The crib coffer-dam leading from the river bank to the obelisk was arranged to support a railroad trestle, the bents of which also served as buttresses for removable timber needles, which were to be left in place as long as the river discharge did not exceed 50,000 second feet. When indications of greater discharge appeared these needles were removed, thus allowing the flood water in excess of 50,000 second feet to pass over the obelisk and coffer-dams, which, of course, made it necessary to discontinue work in the old river-bed until the flood receded. It may be interesting to the reader to learn that these coffer-dams were subjected for weeks at a time to floods of 50,000 second feet passing over their tops and the cost of repairing the slight damage to them did not exceed one thousand dollars.

Obelisk. The use of an obelisk, or a heavy, reinforced concrete mass, for diverting a river, is unique in engineering. Obviously, the general principle is very simple, but the problem included many unknown factors, such as the best way to start the fall, the effect of impact against the surface of the water, possible destruction when the obelisk landed on the river-bed, the effect of "skipping" over the water or of being shifted down-stream by the pressure of the flowing water before finally coming to rest, and also the cushioning effect of the water into which it falls.

Extensive mathematical analyses were made to determine the path of fall, reactions on the pedestal and stresses in the falling obelisk. Finally, a model was built in the hydraulic laboratory of the Carnegie Institute of Technology, to a scale of 1 to 50, to represent a section of the Saguenay River, the diversion channel, and the obelisk. (See Fig. 17.) By means of special recording devices, all of the mathematical analyses were completely checked and the effect of water action in deflecting and cushioning the obelisk were fully determined. It was found that the water provides a perfect cushion and thus makes it unnecessary to anchor large quantities of cushioning material to the face of the huge mass to prevent its breaking when it strikes the river-bed.

One of the important features in the construction of the obelisk was the proper contouring or forming of the river face, which had to be based on accurate soundings of the river-bed. (See Fig. 18.) The high current velocities made the soundings exceedingly difficult and much time and effort were expended in securing accurate results. A

Fig. 17. Model of Saguenay River, Obelisk, and Diversion Channel. Scale 1 to 50.

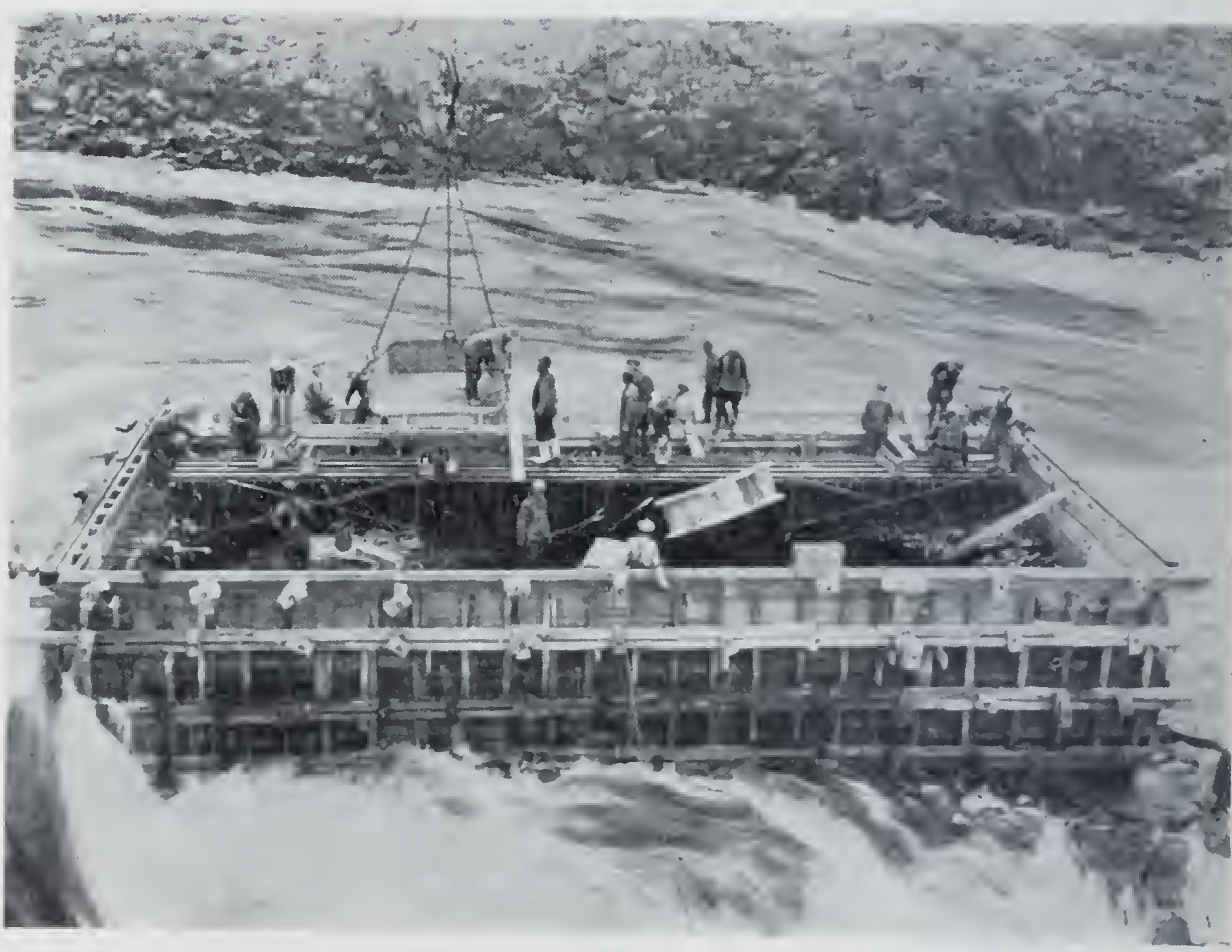

Fig. 18. Building Obelisk Pedestal on Small Island During High-Water Stage.

1000-pound sounding lead, suspended from a cableway and operated by a hoisting-engine, was used.

As finally built, the obelisk was 92 feet high above the pedestal, 45 feet wide and 40 feet in maximum depth. It contains 5400 cubic yards of concrete, weighs 10,950 tons, and was heavily reinforced with about 50 tons of steel, which included 600 pieces of old ¾-inch steel cable. The pedestal was built in the form of two piers, so that by blasting away the smaller pier on the river side, the obelisk, unbalanced to the extent of 75,000,000 foot-pounds, would roll over the cylindrical surface of the remaining pedestal, plunge into the river, and finally land in prone position on the river-bed, thus, in a few seconds, in effect forming a coffer-dam in a stream more than 100 feet wide and 35 feet deep, with a current velocity of about 30 feet a second. (See Fig. 19 and 20.)

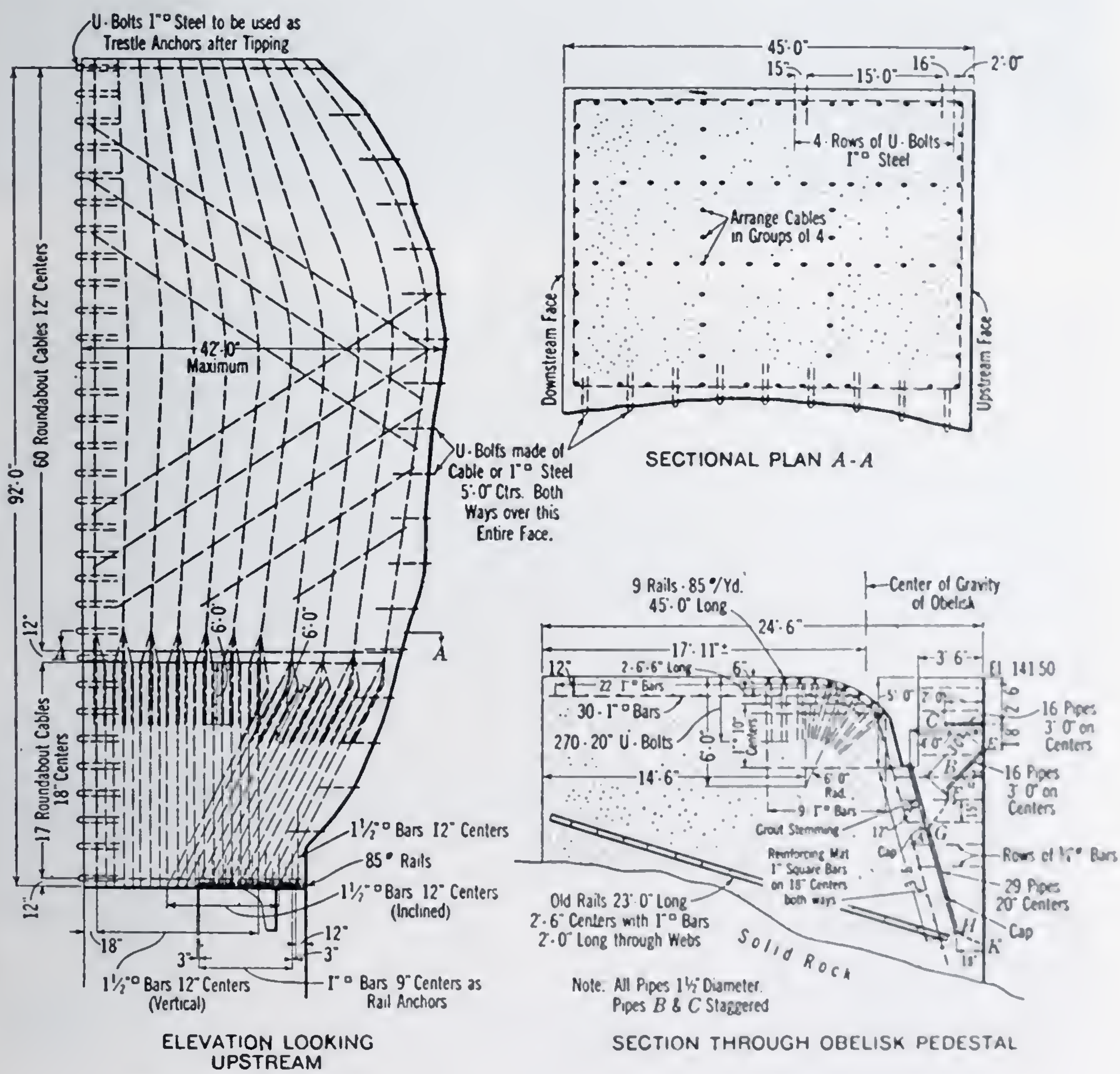

Fig. 19. General Design Features of Obelisk and Pedestal.

Fig. 20. Obelisk Ready for Tipping into Saguenay River. Forms Left on Face To Save Cost of Stripping.

Construction of Dam and Power-House. While these preparations were carried out to divert the river, construction on the dam and power-house proceeded at a rapid pace and according to a carefully laid-out schedule, so that all construction required prior to the time of diversion would be completed. This was principally a matter of placing 350,000 cubic yards of concrete, erecting 2000 tons of structural steel, 680 tons of penstock steel, and 1600 tons of reinforcing steel. (See Fig. 21.) This work was carried on in 1929 and the first part of 1930.

The handling of the unusually large volume of concrete on this type of construction has required a systematic scheduling of mixing, transporting, and placing the concrete. The capacity of the mixer plant is 1600 cubic yards per 10-hour shift delivered from two four-yard Smith mixers. Each mixer is required to operate two minutes after being completely charged with cement and aggregates, after which the concrete is dumped into a four-yard, straight-sided, bottom-dump concrete bucket carried on flat-cars. A concrete train consists of a 40-ton dinky locomotive and two flat-cars, each car carrying four

Fig. 21. Erection of Scroll Cases in Power-House Substructure.

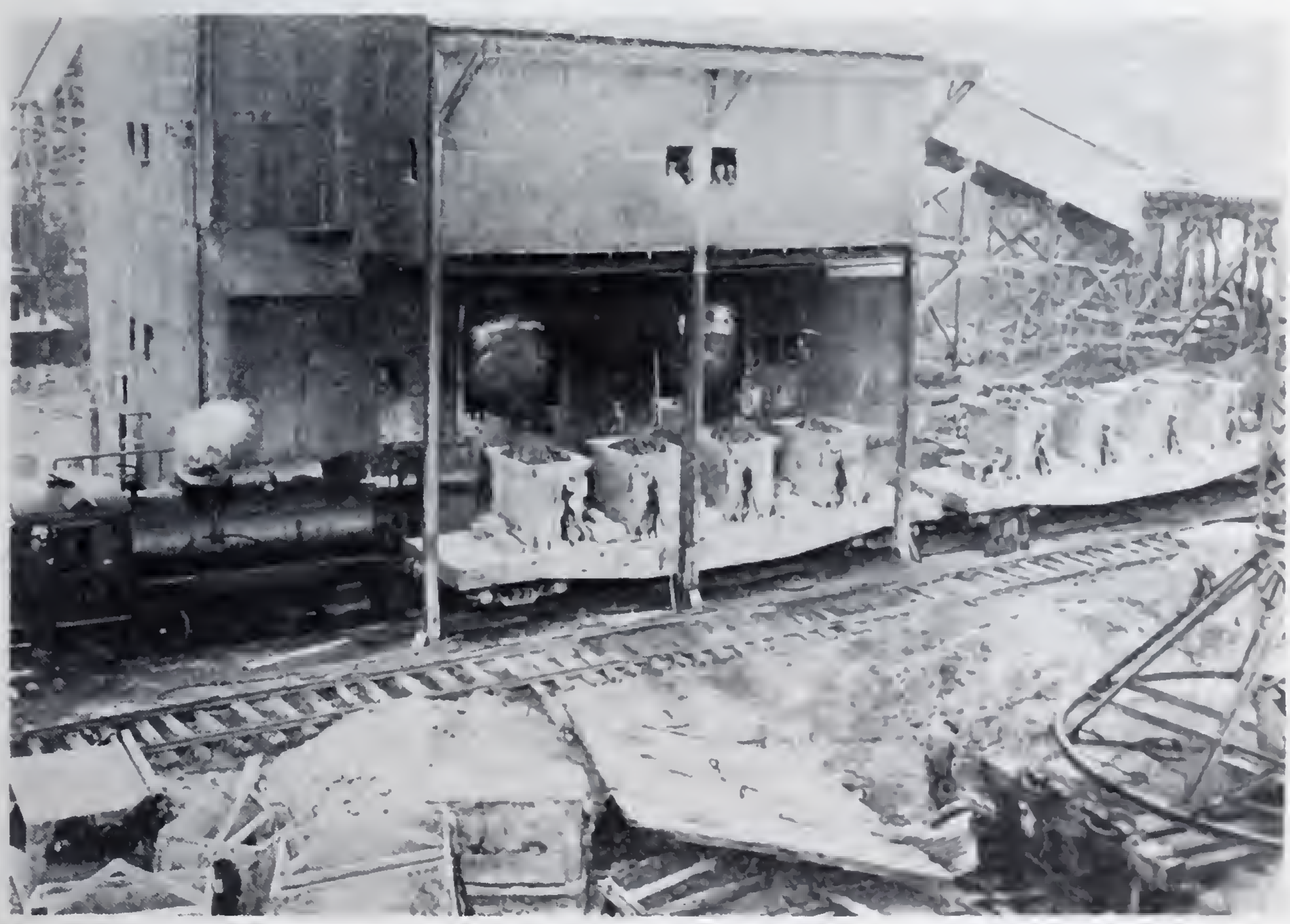

Fig. 22. Typical Concrete Train Being Loaded at Mixer Plant.

buckets, or a total of 32 cubic yards, of concrete. (See Fig. 22.) The maximum haul is one mile to the south shore and four miles to the north shore, to which point the average maximum running time is 15 minutes. Placing operations are so controlled that at no time does the concrete attain an age exceeding 50 minutes before being finally placed. Only a few buckets of concrete have been "spoiled" on the dump. A normal day's run requires six to ten trains and, to facilitate their movement, a train dispatcher is employed to regulate all traffic. He is located in a "crow's-nest" on top of the mixer plant—a point high enough so that he has a view of nearly the entire job and is in prompt communication by telephone with the train crews at all control points.

The handling of concrete at the dam is done by 15-ton stiff-leg and traveler derricks and 20-ton guy derricks, which pick up the buckets and swing them over the forms where the placing crew discharges the concrete. The concrete used on this job is unusually stiff, practically without slump, and requires special vibrating apparatus for compacting it into place. (See Fig. 23.) The concrete was placed

Fig. 23. Vibrating Concrete into Place.

in the curved bucket and on the crest of the dam without using forms on slopes as much as 45 degrees from the horizontal, merely by dumping and vibrating it into place, following established screed and

grade lines, using vibrators of the Electric Tamper and Equipment Company.

The vibrator consists of a ¼-horse-power induction-motor, with an unbalanced rotor, mounted on a wooden tamping foot about 2½ feet long and one foot wide. It is shifted by two men from place to place by means of a short spring-mounted wooden handle. This machine has a vibratory rather than a tamping effect, and its action is apparent for a depth of about 18 inches; it is more effective when the two men who handle it stand on the foot block. In five minutes or less, a four-yard batch of stiff concrete is worked into a mass perfectly homogeneous with that previously placed. It would be impracticable to place concrete as dry as that used on this job with any other method heretofore used. The cost of tamping dry concrete by this method is considerably lower than by other methods and the resulting structures are far superior to those built of wetter concrete, not only as regards strength and density of the concrete, but also in permanency and general appearance of the surfaces, all coupled with lower unit cost of concrete in place.

As indicated in Fig. 8 and 9, a dense layer of concrete is placed in the exposed faces of the dam and a leaner concrete, designated Class C, forms the interior mass, the principal function of which is to provide weight in the gravity structure and resist the comparatively low shearing stresses. At the beginning of a placement (not a "pour") special attention is given not only to the matter of cleaning the joints to avoid the formation of laitance, but to such other factors as insure a water-tight and serviceable structure.

Considerable concreting was done during the winter months, when temperature of 30 degrees below zero obtained, and to prevent freezing of the concrete every precaution was taken by heating the aggregates and water, by using live steam in the mixers, by transporting the concrete under cover, and by covering and steaming the completed freshly placed mass. (See Fig. 24.)

Control of Lake. To permit work on the dam during and after diversion, extensive preparations had been made for controlling the river discharge at Chute à Caron, by manipulating the level of Lake St. John in accordance with a carefully prepared schedule. All available inflow and outflow records of the lake for previous years

Fig. 24. Placing Concrete in Sub-Zero Weather. Steam-Shovel Furnishing Steam for Curing Concrete.

were studied to determine the proper schedule of operation of the flood-gates at Ile Maligne so that, coincident with the date set for diversion at Chute à Caron, the lake level would be low enough to permit the impounding, for a probable period of two or three weeks, of all inflow over and above the amount required for power purposes at Ile Maligne. By such operations, repeated if necessary, a regulated flow limited to 50,000 second feet, the capacity of the sluice tubes and diversion channel, would reach the Chute à Caron project during the closure work, and full preparations could be made for handling all but the most unexpected floods without serious damage to the diversion works, after the excess flow had refilled Lake St. John. (Such refilling occurred twice after the obelisk was tipped and it was necessary in each case to open the flood-gates at Ile Maligne and draw down the lake, with the result that the work in the closure section was flooded out by the water passing over the obelisk and appurtenant coffer-dams until the flow had again been reduced to the capacity of the diversion channel.)

Tipping the Obelisk. During the early part of July the river discharge was very high (up to 100,000 second feet), and it was not until July 23 that conditions were reasonably favorable for tipping the obelisk. On that day the shot was fired which cut away the supporting pier of the obelisk and the huge mass of concrete fell majestically into place and created the biggest man-made splash in history. (See Fig. 25.) Motion pictures were taken of the fall to permit the

Fig. 25. Splash Created by Falling Obelisk.

checking of the computations as to time and path of fall. Impact recorders had been set on the back of the obelisk to measure the shock as it struck the river bottom. The fall was entirely in accordance with the mathematical calculations, the obelisk landing within one inch of its predicted position. Its top was only three feet out of level from highest to lowest corners. The impact recorders showed that the water cushion had absorbed 99.6 per cent. of the energy of the falling mass.

Within 48 hours after the tipping of the obelisk, a railroad trestle had been carried across its top and sealing operations were begun. These consisted of closing the openings, eight feet in width, at each end of the mass, by means of timber stop logs, and of sealing the bottom of the obelisk, using successively large riprap, small riprap,

gravel, and finally sand, along the up-stream face. For this purpose, 20-yard dump-cars were used. The sealing was practically tight within 72 hours after the obelisk was tipped.

Within one week after the obelisk was tipped, the Saguenay went into flood again and several floods up to 100,000 second feet were passed. Favorable conditions for working in the closure section did not again occur until October 4, 1930, when a secondary coffer-dam was built about 400 feet down-stream from the obelisk to intercept the comparatively small leakage through and under the main coffer-dams and under the obelisk; this water was carried in a wooden flume to a point below the site of construction operations on the main dam in the old river-bed. (See Fig. 26.)

Fig. 26. Obelisk in Place and Sealing Operations Completed.

The unwatering at the dam site was accomplished by a battery of large pumps and, when the old river-bed was dry, some surprisingly large pot-holes, dozens of smaller pot-holes, and a tremendous accumulation of loose material were disclosed. (See Fig. 27.) About 10,000 cubic yards of stone and rock had to be excavated from the bed

of the river before concreting operations could begin. At present (October 14, 1930) the work of placing the additional 96,000 cubic yards of concrete required to complete the Chute à Caron dam is well under way, and the problem is mainly a race against time, to beat most of the winter's cold and to have the entire project completed before February 15, 1931, when power must be delivered.

Fig. 27. Unwatered River-Bed at Main Dam and Flume Carrying Leakage from Main Coffer-Dams.

Fig 28 shows the water passing through the sluice tubes under the power-house.

Fig. 29 indicates the progress on the main dam in the old river channel. A feature of this work is that the concrete in the warped surface of the apron was placed without forms. This constitutes an important factor in expediting construction.

Personnel. The design and construction of the Chute à Caron project is being undertaken by the Alcoa Power Company, Ltd., a subsidiary of the Aluminum Company of America. Of the former

Fig. 28. Diverted Water Passing through Sluice Tubes under Power-House.

Fig. 29. Progress on Main Dam in Old River Channel.

company, C. P. Dunn is chief engineer, I. G. Calderwood is general superintendent of construction, and I. E. Burks is concrete technician.

T. J. Bostwick and J. P. Growdon, respectively chief electrical engineer and assistant chief hydraulic engineer of the Aluminum Company of America; W. S. Lee, vice-president and chief engineer of the Duke Power Company; and the writer, are serving as consulting engineers.

Arthur Surveyer, of Montreal, Canada, is collaborating engineer.

Warren J. Mead, of the University of Wisconsin, was consultant on geological and foundation problems.

Owing to the novelty of the obelisk method of closing a river channel, entirely independent mathematical analyses of the action of the obelisk were made by C. P. Dunn, mentioned above; D. J. Bleifuss, hydraulic designing engineer of the Aluminum Company of America; Professor N. C. Riggs, head of the Department of Mechanics, Carnegie Institute of Technology, Pittsburgh; and R. G. Sturm of the Research Laboratory of the Aluminum Company of America.

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MICROSCOPIC INVESTIGATION OF METALS*

By V. N. Krivobok†

The conference arranged by the Engineers' Society of Western Pennsylvania is indeed a good proof that the testing of materials, radiography, and, finally, metallurgy and metallography, are no longer to be considered as three separate sciences. They are the three definite, in a way independent and at the same time closely associated, branches of the great, fascinating subject that may properly be called the science of metals.

These three supplement each other, and at times contradict each other, but still they have but one aim, one purpose—to enable us to grasp the science of metals from all possible angles and, having done so, to use it to our advantage.

I believe that I shall voice the opinion of almost every speaker that the greatest difficulty is not in the preparation of the paper, but in the selection of a topic. As I anticipated, I see in the audience Dr. Johnson and Dr. Whetzel, who are so well known in the profession. There are, probably, in the audience many more gentlemen of high standing in the field of metallurgy. On the other hand, there are probably some engineers who somehow have escaped the fascination of metallurgy and are, therefore, less informed on the subject. And so, in selecting my topic, I must aim at satisfying all, and you all can see what a difficult problem that is.

There are at least four main purposes which fully justify the existence of metallurgy. First of all, there is the inspection of engineering materials, long used by engineers for numerous purposes. Often this is routine work, but important and necessary despite its monotony. Second, there is the kind of work that is often misnamed "plant research," but which, in reality, means following up different troubles that occur daily in the life of any manufacturing establishment. Sometimes it is a question of improperly prepared materials; sometimes the difficulty lies with the heat treatments; sometimes it is the conditions of service. In all cases, the trouble has to be investigated, its cause determined, and its further occurrence prevented—a truly important function. The third purpose is a truly creative work

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of developing new materials and new alloys with which to supplement or to replace the old ones. Often these alloys give promise either from an engineering or an economic standpoint. Still more often their development is demanded by various activities of engineering. This is the work, fascinating work, which we metallurgists are called upon to do, and which we can do best only when we work hand in hand with men like the other speakers at this conference—Mr. Templin, representing the testing of materials, and Mr. Clark, as the champion of the new science of radiography. The last, but by no means the least, is the true research, that branch of metallurgical science which does not strive to produce immediate return on the money and effort invested in it, but accumulates reliable scientific information which is carefully put aside for future use, for no one can tell how much it will mean to-morrow even though it may seem useless to-day.

I have named only four main branches of work, not because they fully cover the field of activities, but because even a condensed discourse on these four "activities" will be indicative of the immense importance of metallurgical science.

According to my simplified outline, the first use to which metallography can be put is the inspection of materials, such as steels, cast-irons, brasses, bronzes, etc., of which tons are used every day. Not a small part of the inspection is watching the metallographic characteristics of the metal. You probably know that every metal has its own characteristics, depending on its preparation and treatment. Consequently, by taking a sample and having it properly prepared for microscopic studies, we can form a very definite opinion—at least in most cases—as to the previous history of the sample and its suitability for a given purpose. I used the phrase "properly prepared" advisedly for, unless this precaution is exercised, a very embarrassing situation might arise. If the process of preparation is carried on by an inexperienced person, the metal is made to contain a large number of infinitely small holes that look like black spots when observed under the microscope. When a piece of steel contains a large number of non-metallic inclusions, which, by the way, are commonly called "dirt," these inclusions also look like black spots under the microscope, and for an inexperienced eye it is rather an easy thing to pronounce the steel "dirty," while, in reality, it was mishandled and abused during the preparation (polishing) of the sample. During my

metallurgical career, I have witnessed cases when perfectly good steel was adjudged "dirty" on the strength of very questionable evidence.

A few minutes ago I said that practically every metal has its own metallographic characteristics. Perhaps not all of you know these characteristic appearances of different metals after different treatments, and it is for the benefit of these that I permit myself to show a few photomicrographs of characteristic structures. These illustrations, by the way, were prepared by taking a representative piece of metal, polishing it to the highest degree attainable, and then treating the surface with certain acids, which, acting differently upon different constituents of the metal, will, consequently, reveal its structure. Fig. 1 shows the structure of pure iron, a very definite structure which could not possibly be mistaken for the structure of mild steel, as shown in Fig. 2. A careless metallurgist is quite liable to mistreat this steel, as, for example, by overheating, the results being shown in Fig. 3. The steel in the annealed state is ductile, fairly strong, easily deformed by cold working, and deprived of hardness, metallurgically speaking. It is used for many engineering purposes and many structural steels would look like this under the microscope. However, we need steels for other purposes, too. We need hard metals for tools or for mining implements, for example. To obtain the best results and secure the longest life we have to use either carbon steel, heat treated

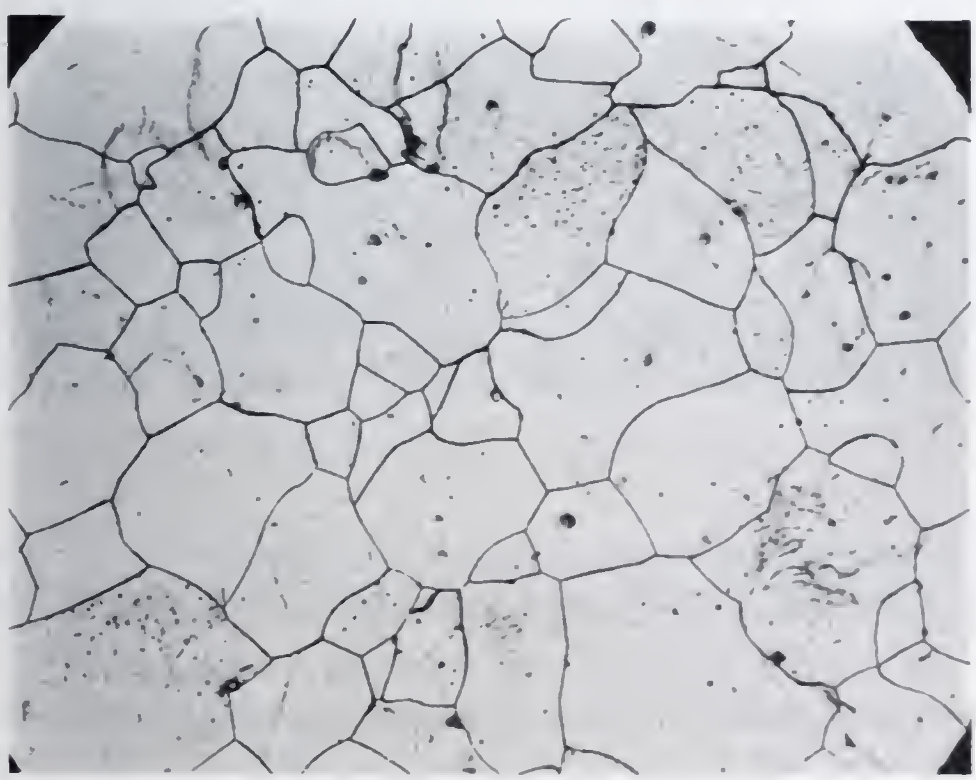

Fig. 1. Structure of Pure Iron.

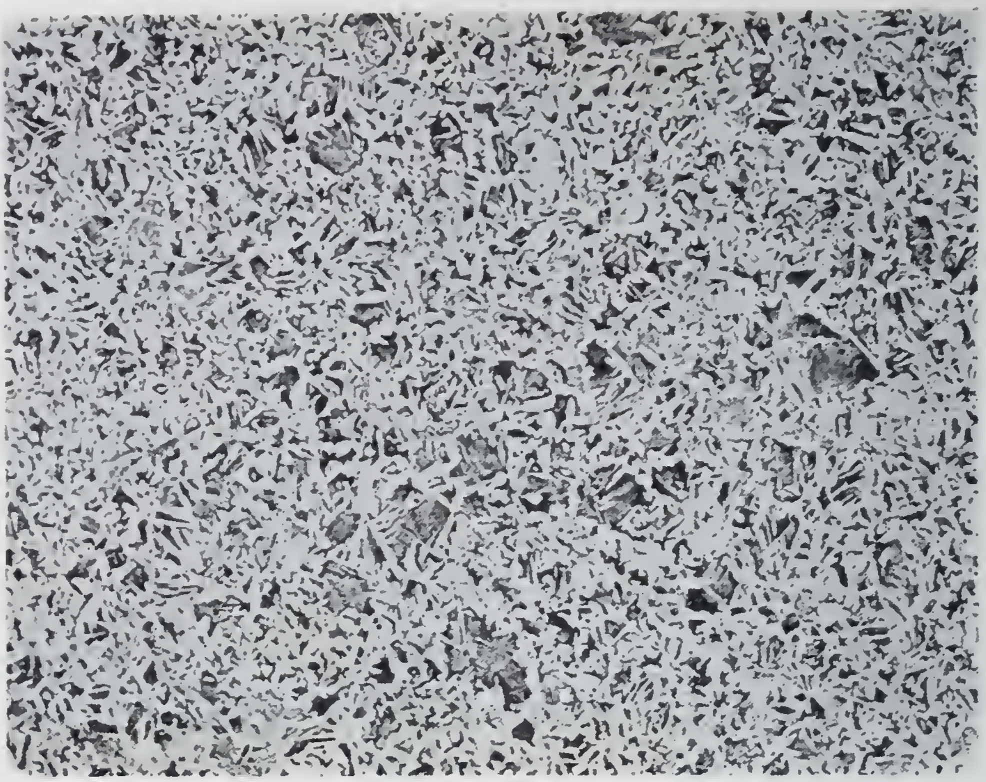

Fig. 2. Structure of Mild Steel.

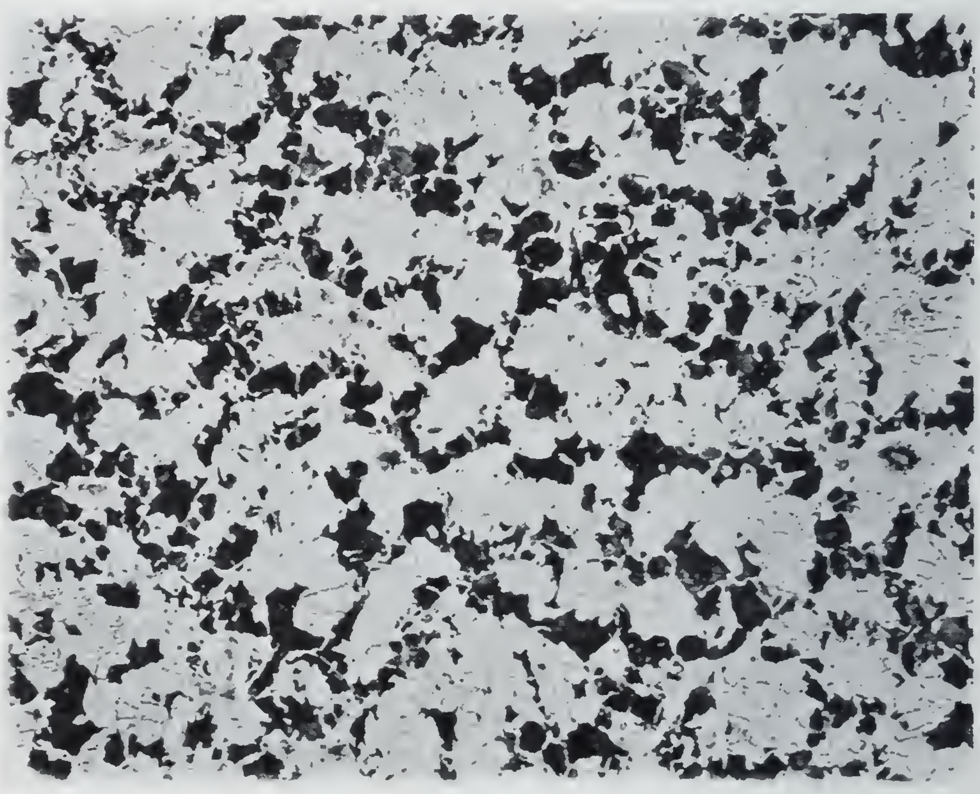

Fig. 3. Results of Overheating.

in the proper fashion, or resort to the use of special steels. The treatment of carbon steel to obtain the maximum hardness consists in rapid cooling from a high temperature, followed, sometimes, by a slight reheating. A treatment of this sort produces a structure such as is shown in Fig. 4. The structure of this steel is exceedingly fine and although the previous illustrations show the structure of steels quite

well when magnified 250 times, we require in this case a much higher magnification, approximately 2000 times, in order to view with clearness the structure of the steel. Consequently, this job of the metallurgist—the inspection of materials through a carefully conducted and thoroughly understood study of structures—is obviously an important one. However, it must not be concluded that merely because a piece of steel shows the structure that it should (taking into consideration

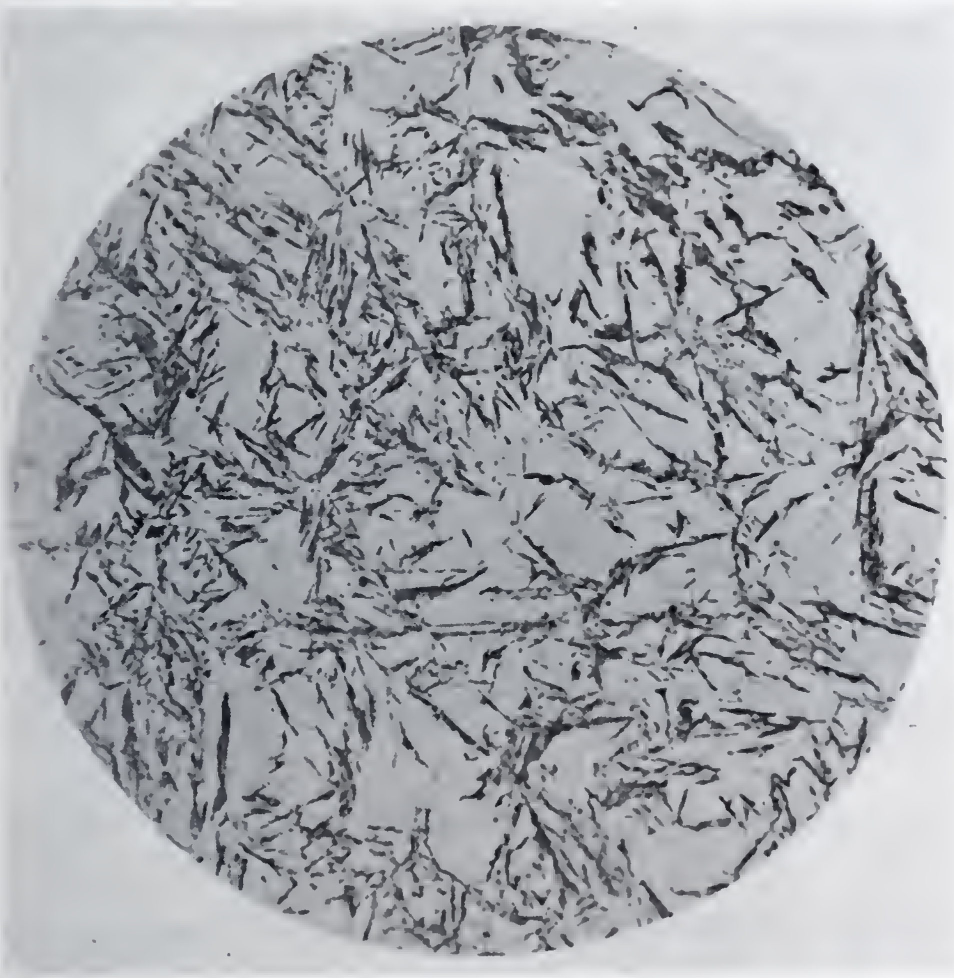

Fig. 4. Carbon Steel Treated to Produce Hardness.

the heat treatment received), it is suitable for the purpose for which it is intended. Several other characteristics, among them segregation in the ingot, must be considered. Also, although a few minutes ago I took the liberty of cautioning you in regard to careless handling of the "dirt" in steels, I, myself, nevertheless, believe that the properly conducted inspection in regard to "dirt" is unquestionably of paramount importance.

Perhaps the significance of my remarks will be easier to grasp if I permit myself to dwell for a minute or two upon some theoretical questions concerning all metals and all alloys.

When an ingot is poured, solidification starts from certain points in the metal and proceeds in every direction. We have good evidence that crystallization of metals does not proceed with uniform rapidity in every direction, but that solidification takes place by forming some very intricate crystalline formations such as are shown in Fig. 5. It required a great deal of careful handling in order to photograph these crystals, as I wished to have them, in three dimensions. This illustration shows a crystal which was found in the cavity of a very large ingot. If you were able to stop solidification while the contents of the

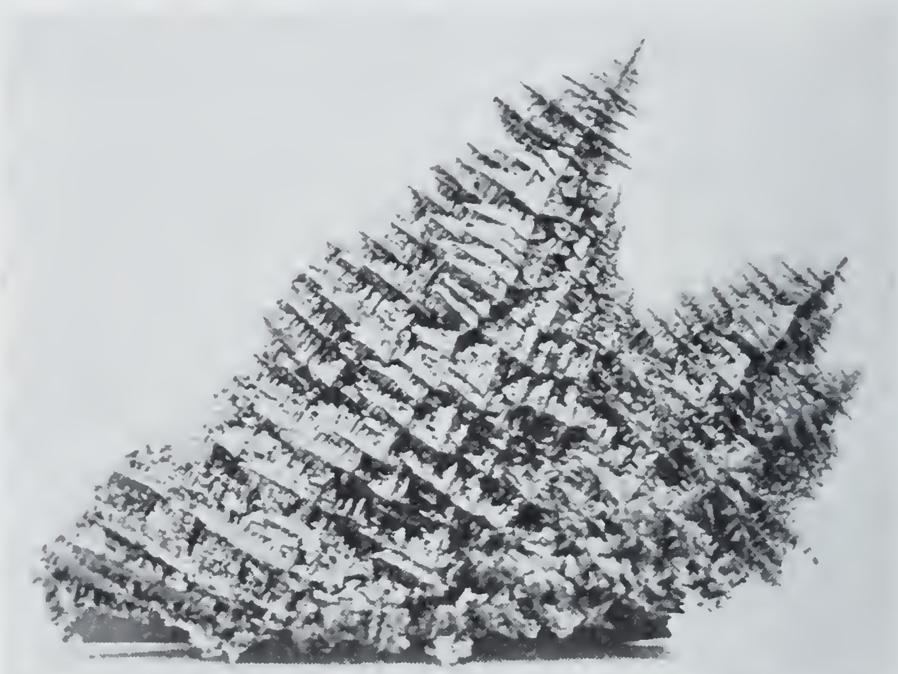

Fig. 5. Crystalline Formations in Steel.

mold were still half solid and half liquid, and to pump out the liquid, leaving the solid crystals behind, you would find that the solid portion of the ingot is made up of a great many crystalline formations like the one illustrated. However, when complete solidification has taken place, all the minute spaces among these crystalline formations are filled up, and we observe a number of fully grown crystals, closely interlocked with each other. While the crystalline formation is going on, the crystals themselves are formed in strict conformity to certain definite, physico-chemical laws.

If we analyzed that part of the liquid metal which we pumped out of the half-solidified ingot, we would find that the analysis of the liquid shows a great deal more impurities than the analysis of the solid. It simply means that the greatest amount of impurities is found in the portions of the metal which solidify last. In other

words, segregation takes place during solidification. If we take, for example, a piece of cast-steel, polish it in the regular way, and etch it with a certain reagent, we will observe the structure (shown in Fig. 6) that represents the cross-section of the crystalline formations previously shown. The segregation means an uneven distribution of such elements as carbon, manganese, etc., and the difference in actual amounts of such "impurities" from one spot to another may be, and indeed sometimes is, very large.

Here it is my opportunity to say a few words to the engineers who are dealing with specifications. Most of the specifications are very precise, as they should be, but, unfortunately, some of us are

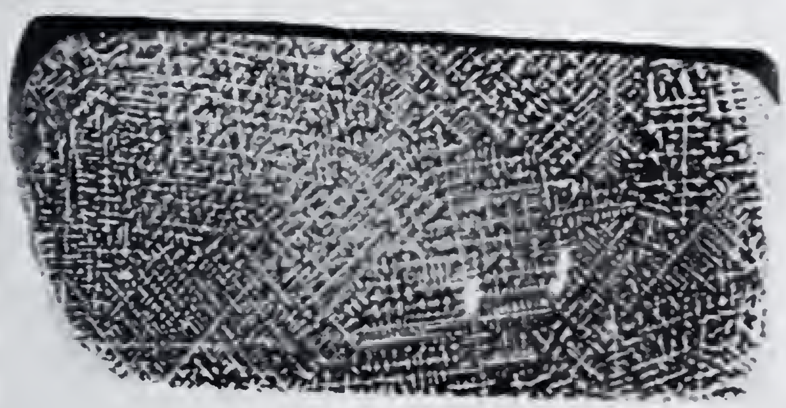

Fig. 6. Cross-Section of Crystalline Formations in Steel.

inclined to use these specifications without much careful thinking. For example, a certain specification for a certain steel calls for sulphur, maximum 0.05 per cent., or phosphorus not more than 0.04 per cent. An inspector, who might be in slightly bad humor, let us say, for example, because of indigestion, gets the report of the chemical laboratory and finds that phosphorus is 0.05 or 0.06 per cent., and promptly declines to accept the shipment. True enough, in most cases, such trivial differences in opinion are adjusted by higher officials, but in the meantime a great deal of inconvenience is caused by the delay in shipment, etc.

Let us visualize what we do when we make a chemical analysis of a piece of metal. The procedure is fairly simple. Some one takes a piece of steel, carries it to a machine-shop where the drillings are obtained, and then sends these drillings to the chemical laboratory, where the chemist analyzes them, taking care, if he is a good chemist, that they are well mixed up before he secures an actual sample. The

chemical analysis, so obtained, represents the *average* of a given element per unit weight, that is to say, per unit volume. But it does not tell us anything about the distribution of that element. I assure you that in many an ingot the difference in composition due to the mode of solidification, which it was my pleasure to describe to you, is a great deal greater than the difference between the findings of the chemist and the specification which is considered sufficient to reject the shipment. It is far from my desire to imply that the specifications do no good. Of course, they are of importance, and we could not very well do without them; but let us be less dogmatic and exercise good sense when dealing with matters of this sort.

So far I have been talking of the impurities which form so-called "solid solution" with iron. The same thing, however, applies to non-metallic impurities, which consist mostly of oxids, sulphids, or silicates of iron and manganese. In some cases we must pay a great deal of attention to the distribution of non-metallic inclusions. The same amount of inclusions can be evenly distributed throughout the mass of metal and do little or no harm. Sometimes, however, they will be present in the form of streaks and therefore create the potential source of weakness. Non-metallic inclusions often have a structure of their own and they are, at times, quite complex. (See Fig. 7.) Sometimes these inclusions, because of their aggregation, are the starting points for cracks. Fatigue failures, familiar to all of us, have been, in some cases, traced to inclusions.

The second phase of the metallographist's work, as I already mentioned, is the inspection and investigation of material, not before it was put in service, but after a failure has occurred. The most obvi-

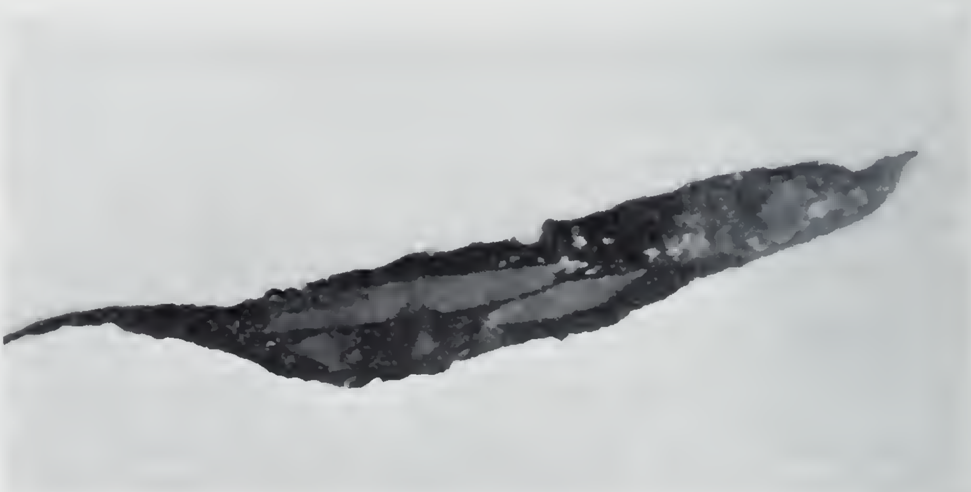

Fig. 7. Non-Metallic Inclusions.

ous aim of such work is to prevent the recurrence of similar failures. Some of the problems of this sort are very baffling, as, for example, transverse fissures in rails, or boiler failures, or failures in superheater tubes. We know a great deal about them, but very little, as yet, about how to prevent them. I shall say no more about this matter, but it could be made the subject of a very long lecture in itself.

Our duties under the third class that I mentioned can be traced directly to you engineers. Engineers always invent new uses for materials and, unfortunately (or perhaps it would be better to say, fortunately), to the metallurgist falls the job of finding the material that will accomplish the required work. In order to reduce corrosion, we had to invent stainless steels; in order to enable the engineer to use steels at high temperatures, we had to produce chromium-nickel alloys. In this way the progress in standards of living is assured and the progress in engineering and metallurgy made obligatory. I may proudly add that the metallurgists deserve a lot of recognition for their painstaking efforts to produce steels and alloys that will serve under very difficult conditions, created by our own ingenuity.

Unfortunately, however, not all engineers realize that if a certain steel has been satisfactorily developed for a very definite purpose it does not mean that the same steel will do equally well under different conditions. In short, special steels and special alloys should not be used without critical discrimination. Recently, some very pathetic failures have occurred in an extremely useful alloy and the alloy, most unfortunately, received a bad reputation. I wonder what the public in general would have said if a baseball team used foot-ball players during the "World's Series"! As it happened, the alloy in question should not have been used, because it was designed for different service. Is it out of order for me, therefore, to plead with you engineers to use us metallurgists in a consulting capacity whenever you have to meet certain specifications and use the material under certain conditions? A self-respecting metallurgist will never adopt the salesman's line of conversation. In fact, I am quite certain that our advice would often discourage the use of certain steels for certain purposes.

As an illustration, recently developed chromium-nickel alloys have extremely good resistance to oxidation at high temperatures, and are ideally suited for installations of this type. However, when

the same steel is installed in places where it is subjected to direct action of gases (and our investigations point out that sulphur-bearing gases are especially harmful) the alloy is affected and thus rendered unsuitable for the purpose. This illustrates the difficulty to which I referred previously as conditions of service.

That the treatment of steels and alloys can be conducted in such a manner as to ruin them is, of course, well known. A very familiar example would be so-called "burnt" steel; that is, steel overheated to such an extent that partial melting has taken place. In certain classes of alloy steels the product can be ruined without actual melting. Let us take, for example, either high-chromium or chromium-nickel alloys. Many kinds of useful implements are made of these alloys and the variety of mechanical and heat treatments to which these steels are subjected is very large. Some of the alloys are rather difficult to roll, and a fairly high rolling temperature is necessary. If the temperature of rolling is not carefully watched and becomes too high, a very definite constituent is formed in the steel, completely ruining it for any purpose. (See Fig. 8.) This particular new constituent, a

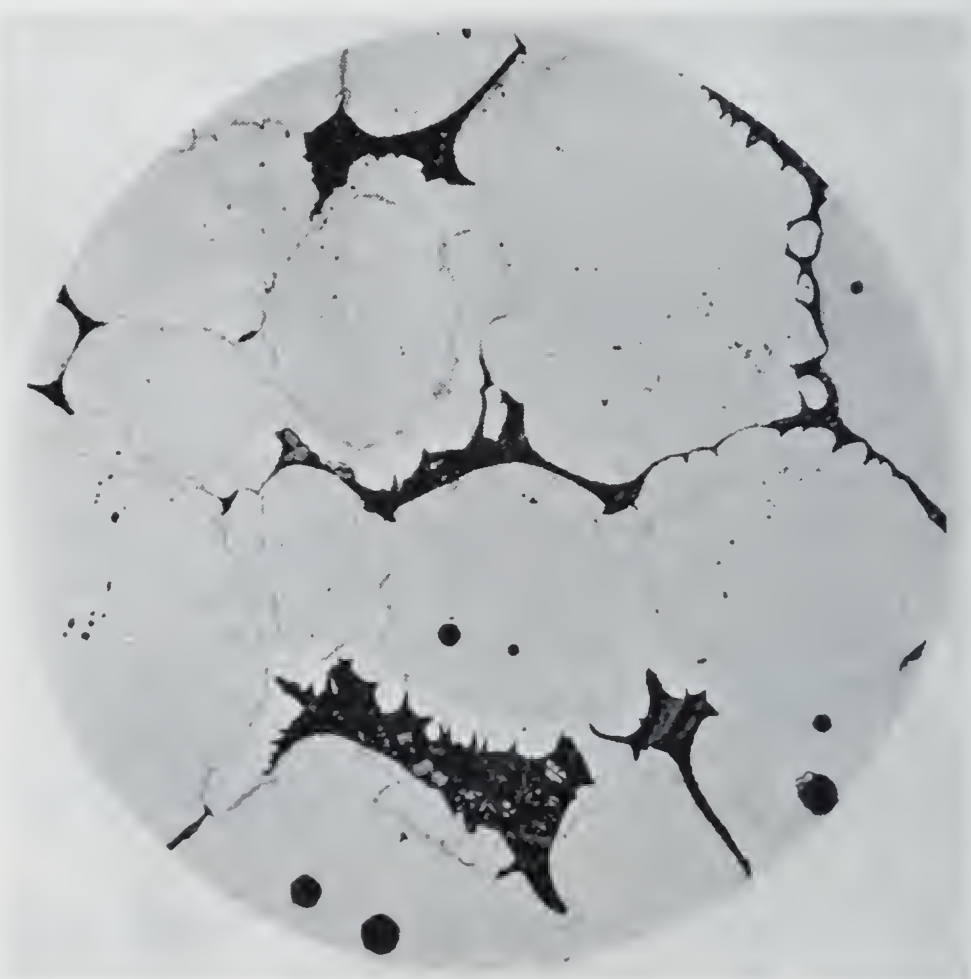

Fig. 8. Alloy Steel Injured by Rolling at High Temperature.

result of so-called "peritectic" reaction, is formed around the grains, separating, as it were, one grain from the other. Steel with this constituent shows no strength, and even a Brinell impression will cause the grains underneath it to separate and fall apart. (See Fig. 9.)

Purely mechanical conditions of service which sometimes bring about the failure are well illustrated in Fig. 10. This is a sample

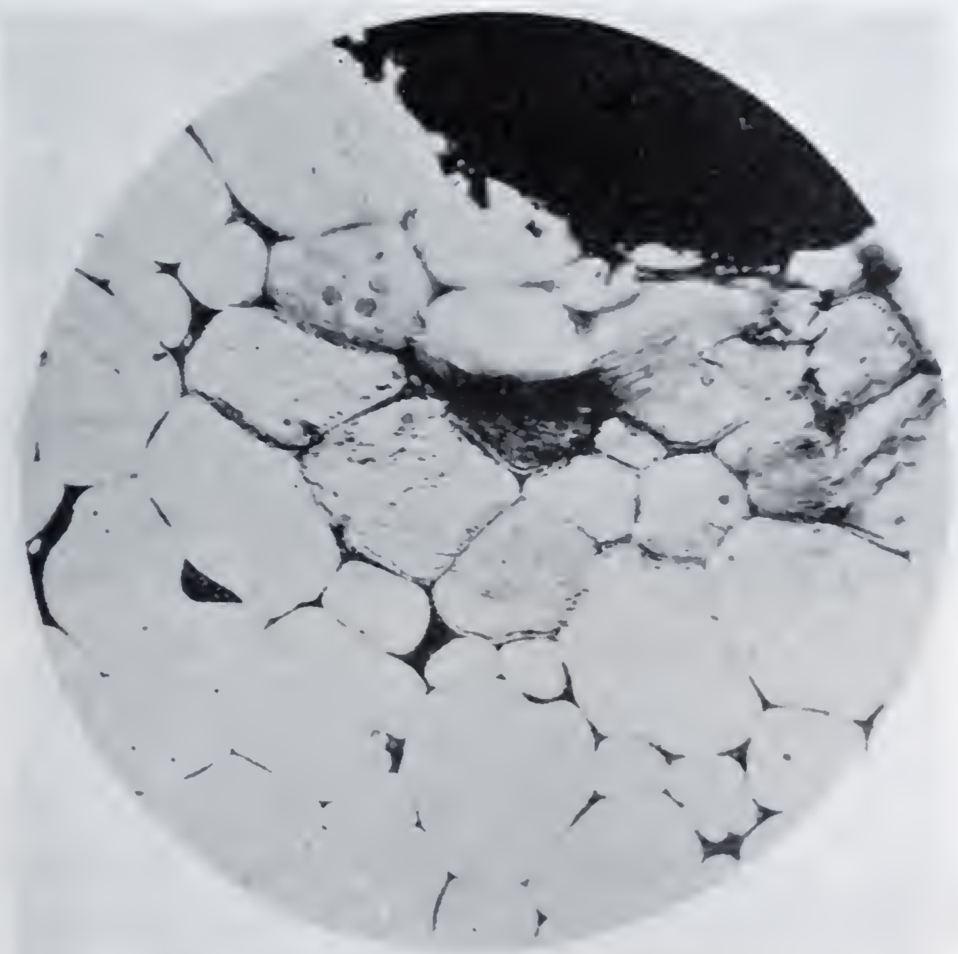

Fig. 9. Failure under Brinell Test.

taken from a high-manganese steel rail which was so deformed by constant battering that it first developed lines of deformation along which the decomposition of the steel has taken place, resulting in ultimate failure.

My remarks and illustrations are not used for the purpose of conveying the idea that investigation of the failures is as simple and as easy as might be inferred. In practically all cases we have to labor most diligently, and oftentimes are forced to carry on a most extensive search before we finally find the root of the difficulty. We gradually conquer this field and the number of unsolved "crimes" against safety becomes smaller with each year.

Fig. 10. Failure of Manganese Steel Rail.

I mentioned the third application of metallography which deals with the development of new materials and alloys. The work of the metallographist may be conducted in several ways. For example, we may know the conditions of service and undertake to find a material that will withstand them; or we may start from the other end—develop a new material, find out its characteristics, and then apply it to a certain engineering installation.

So far, I have considered mostly steels, and have not mentioned non-ferrous alloys. One of the latter that may serve as a fascinating example of engineering and metallurgical development is "duralumin," an alloy which has found wide application in many fields and especially in aviation. "Duralumin" is an alloy of aluminum to which are added some five per cent. of copper, with a little magnesium and manganese. When this alloy is quenched from about 525 degrees C. and allowed to "age," its properties change. The alloy becomes much stronger and harder, while it loses but little of its ductility. The process of "aging" thus proved most beneficial and received the attention of the foremost men in our country. The theory has been

evolved (and proved) that during the "aging" process a certain amount of added ingredients precipitates out of solid solution and becomes dispersed throughout the metallic crystals, acting, when under load, as an obstruction to slippage along crystallographic planes, thus rendering the alloy stronger. Unfortunately, I do not have in my collection a photograph showing the precipitation in "duralumin" or in any other aluminum alloy. Similar phenomena take place in some special steels; in fact, I am convinced that most of the alloys of the solid-solution type would react to the age-hardening treatment under certain conditions. Fig. 11 and 12 show a definite precipitation in manganese steels accompanied by very definite change in properties such as hardness and strength. These and the subsequent illustrations in this paper are shown with a magnification of 2400 diameters. Fig. 11 shows the precipitation in its early stages. The precipitated particles are small and give the impression of orderly arrangement due to their precipitation along crystallographic planes. If the same precipitation is allowed to proceed further, as in Fig. 12, the precipitated particles become agglomerated and the properties of the material are corre-

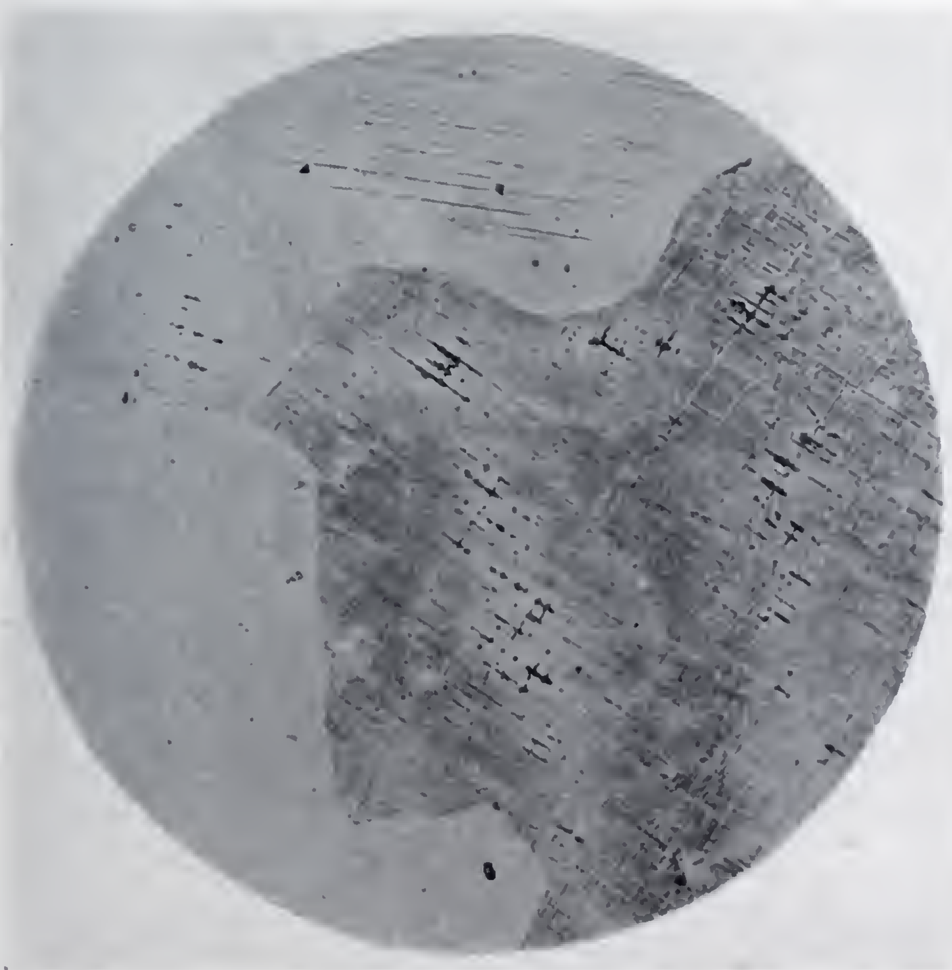

Fig. 11. Incipient Precipitation in Manganese Steel.

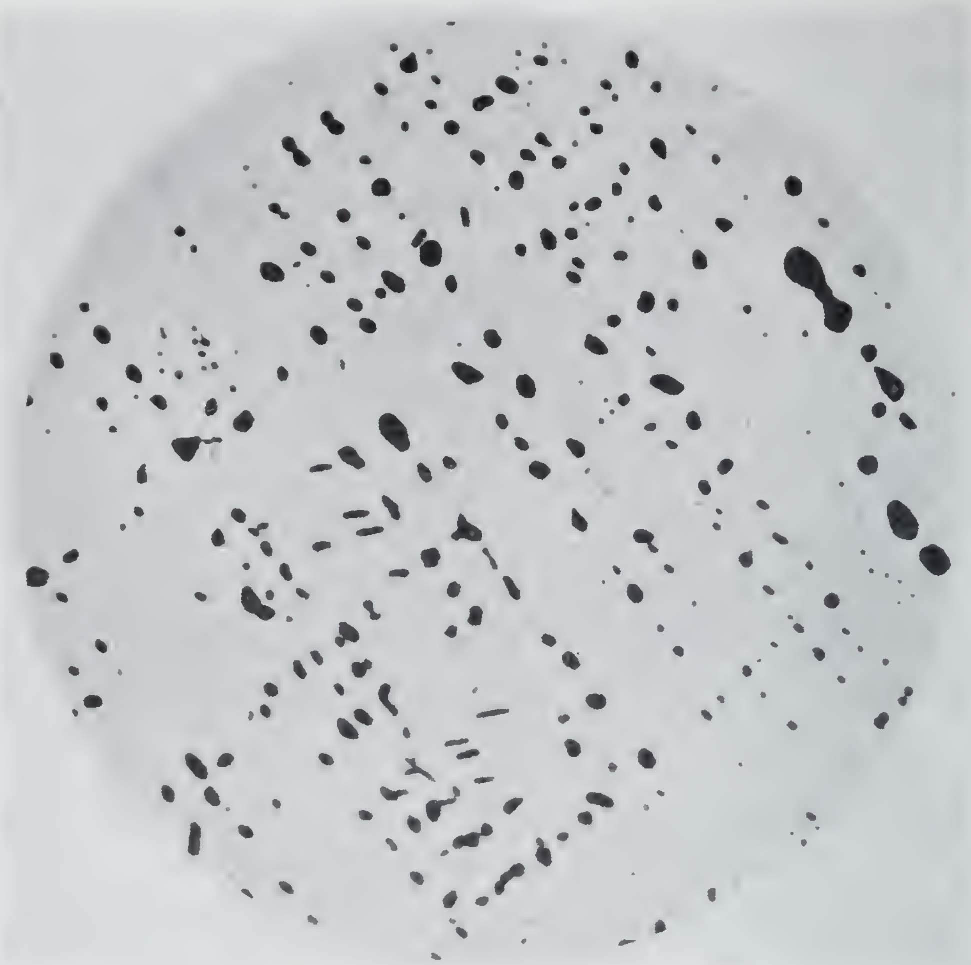

Fig. 12. Agglomeration of Precipitated Particles.

spondingly changed. In other words, the distribution and the size of the precipitated particles have a very definite influence on the properties of the material.

I could cite many other examples of similar nature, most of which are indeed fascinating—the hardening of copper, the studies of multiple aluminum alloys, bearing metals, the new hardening process known as nitriding, tungsten carbid tools, nickel-iron alloys for precision instruments, magnesium alloys, etc. A new book on aluminum* reads like the stories of the "Thousand and One Nights."

To state that the art of treating alloys is confined to our days would be incorrect. I am a very proud possessor of a most interesting collection of ancient armor, some of it belonging to the fourteenth century, and some to the thirteenth century, while several of the pieces were made in the eleventh century, and a prize one in the seventh century. By studying these pieces, I was able to trace the art of heat treatment back to those early days. In fact, the very process that I have just described is very similar to one used ages ago in fabrication of swords that became famous under the name of "Damascus steel."

*Aluminum Industry, by J. D. Edwards *and others*. 2 v. 1930. McGraw, New York.

It is time we came to the fourth application—the scientific metallography which is incessantly carried on in many beautifully appointed laboratories and which seeks no immediate return on the labor spent in its behalf. To illustrate the numerous activities pursued in these fields would be altogether impossible. It would be fitting, however, if I mentioned as a typical example of theoretical and scientific metallography, the question which the dean of American metallurgists, Dr. Albert Sauveur, has asked for thirty odd years. What is the nature of martensite, that constituent which we find in hardened steels? As yet, we have not agreed on the answer, but a great deal of work has been done which throws much light on the complicated nature of seemingly simple operation. Fig. 13 shows a typical martensite. The true nature of this constituent is not revealed until we use very high magnification. It was not so long ago that we first learned how to make use of high magnification. When we resorted to it, we were able to see that the very fine needle-like structure of martensite represents the decomposition of the originally austenitic body along the cleavage planes. We are now aware that this decomposition, brought

Fig. 13. Typical Martensite.

about, among other things, by internal stresses, assumes a state in which the products of decomposition are found in fine dispersion. Should we allow the decomposition to proceed further, it will have, as its result, the formation of another well known constituent, martensite, illustrated in Fig. 14 and 15. We can follow the whole process of martensitic formation and decomposition as further shown in Fig. 16 and 17, following, in reality, the whole process of heat treatment.

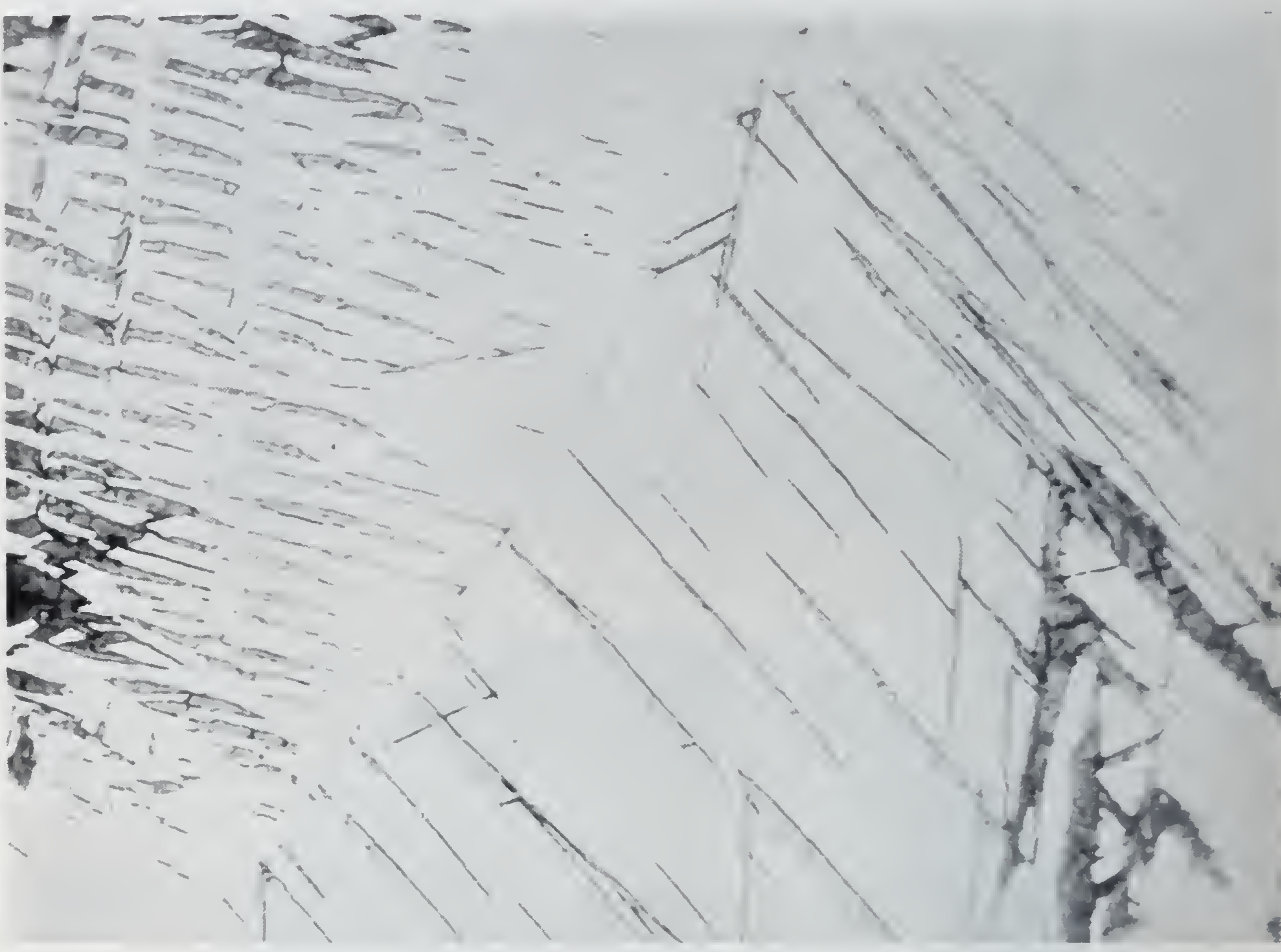

Fig. 14. Martensite, with Decomposition along Cleavage Planes.

The question of martensite is, as I said before, a debatable one and probably some of you will not agree with my simple interpretation, but it is a typical example of scientific metallography. I do not exaggerate when I say that the study of martensite (and the hardening process in general) has led to many most useful results, such as the question of internal stresses, of cooling rates, and of proper media for hardening.

Some ten years ago it was my privilege and pleasure to visit certain western metallurgical plants of this country. At that time I was quite young, inexperienced, and in the possession of a receptive, but not critical, mind. I kept extensive notes throughout my trip. When

Fig. 15. Coarse Martensite.

Fig 16. Further Decomposition of Martensite.

I looked through these notes just a short while ago I was amazed at the amount of "technical" information which I religiously noted in my note-book, but the significance of which still remains obscure. In fact, some of the statements are not even printable.

Two years ago I made another trip and kept another note-book, and found that the methods of work, methods of approach, methods of tackling different problems, are no longer in the hands of illiterate

Fig. 17. Last Stage of Decomposition of Steel.

(metallurgically speaking) persons, but are based on metallurgical common-sense and knowledge, sometimes, of course, quite limited. This change was inevitable because of economical considerations, the demands from the engineering profession, and so on. It has come through fundamental education and dissemination of useful, correct, and reliable technical information—the function so admirably and unselfishly performed by our national engineering societies, as well as by many professional periodicals. However, a tired man is very apt to fall asleep over a book or a magazine. This is less easy in the lecture hall and this, in itself, is a good reason for meetings of this sort.

DUST REMOVAL FROM INDUSTRIAL GASES BY THE COTTRELL PROCESS OF ELECTRICAL PRECIPITATION*

By C. W. Hedberg†

INTRODUCTION

In the two decades which have elapsed since 1908 when Dr. F. G. Cottrell utilized what, up until then, had been simply interesting phenomena, to eliminate the nuisance resulting from the discharge of waste gases containing sulphuric acid mist at a Pacific coast chemical plant, the Cottrell process of electrical precipitation has become established as one of the leading methods for removal of suspended particles from gases. While accurate statistics are not available, it is estimated that the number of installations consisting of one or more unit precipitators throughout the world is well in excess of a thousand and that the installed capacity is upwards of 30,000,000 cubic feet of gas per minute.

Prior to 1923 most of the installed capacity was in precipitators for recovering values from waste gases in non-ferrous smelting, for dust removal from gases from Portland cement kilns, and for miscellaneous uses in the sulphuric acid industry. Since that year, several other industries have become important users so that now (and this applies only to the operating company with which the writer is associated) the installations are classified into seven different groups. Fig. 1 shows the relative capacity in each of these groups based on a total of 13,750,000 cubic feet per minute at the end of 1930.

Of these groups, three appear to be of particular interest if we use as a measure the rate of increase in numbers of recent installations and the extent to which consideration is being given to new applications. These are the detarring of manufactured gas, removal of fly ash from boiler gases and cleaning of blast-furnace gas.

DETARRING OF MANUFACTURED GAS

Fig. 2 shows graphically the rate of increase in installed capacity in this particular field since 1924. During the first three years most of the installations were for detarring carbureted water-gas. At

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Fig. 1. Distribution of Installed Capacity of Cottrell Electrical Precipitators.

present, however, most of them are going into by-product coke-oven plants.

In the latter field, experience has shown that a removal of between 95 and 98 per cent. of the tar content in the gas at the point of treatment is sufficient for subsequent operations. Because of this, the cleaning is done in a single stage in equipment, the essentials of which are shown in Fig. 3. Depending on gas volume, available space, piping, etc., the required capacity is installed in units of a size and number to give the simplest and most economical and flexible arrangement. It is general practice to install them after the primary coolers, and they can be either on the suction side of the exhauster—in which case they are frequently erected in the open—or on the pressure side, which may place them in either the exhauster or the by-product building.

The individual units are of the pipe type and consist of a cylindrical shell with a header plate in the upper portion. This header

supports a number of pipes which are either six or eight inches in diameter and nine feet long. Near the bottom there is a spacer frame in which the pipes are clamped in a vertical position.

In each pipe there hangs a weighted rod supported from a bus frame mounted on insulators. The insulators are installed in separate

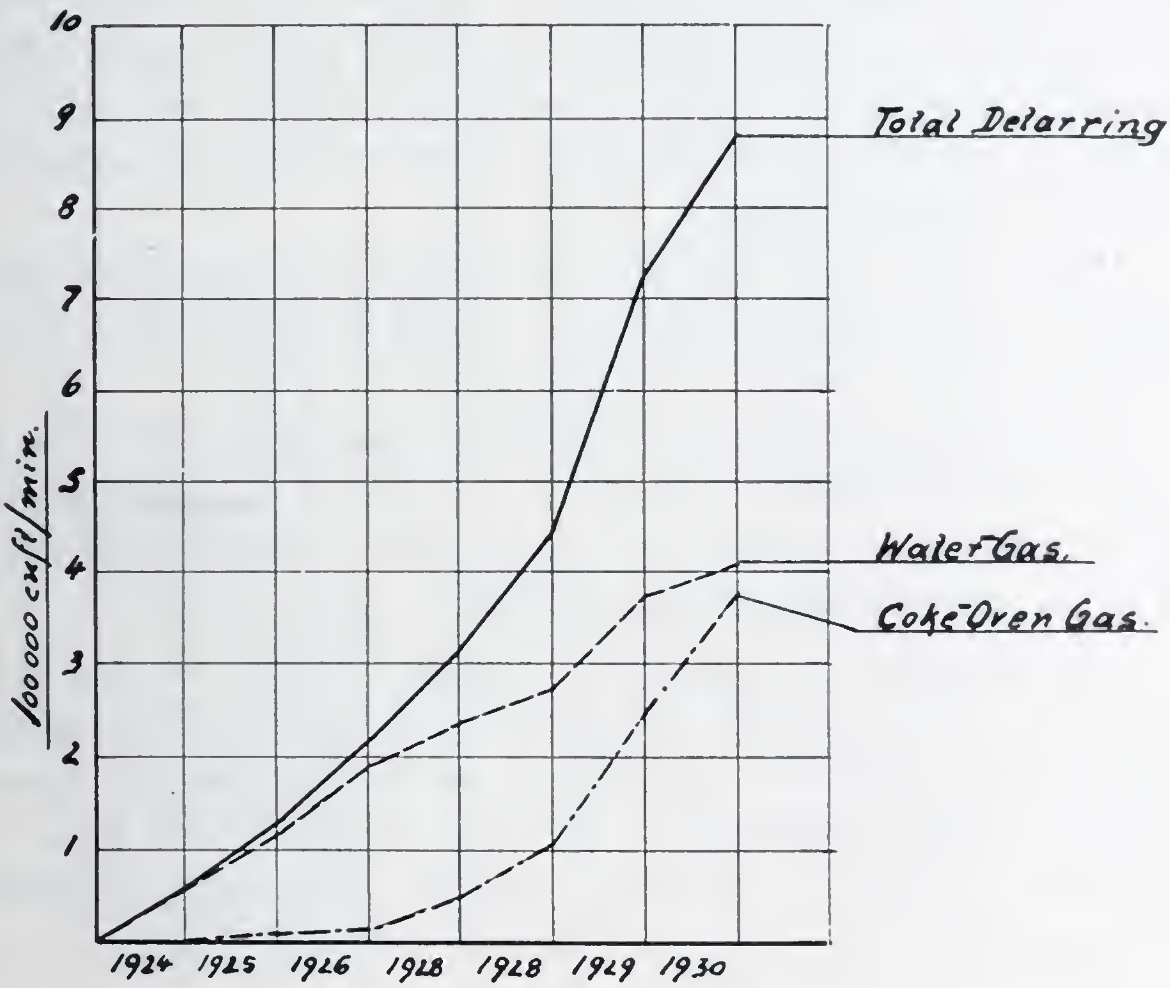

Fig. 2. Curve Showing Installed Capacity of Precipitators for Detarring Manufactured Gas.

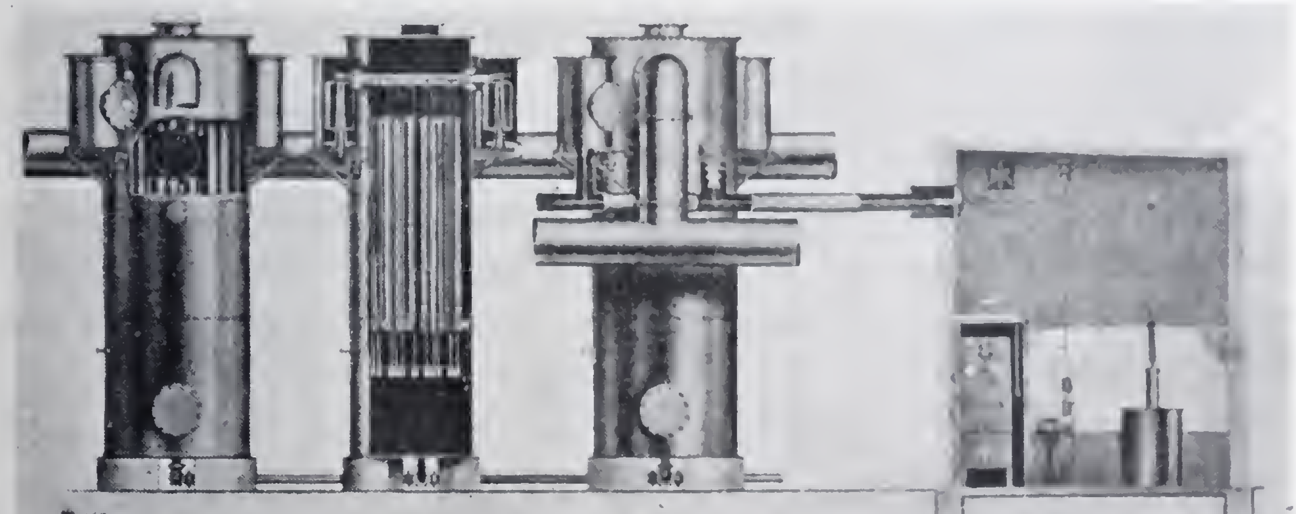

Fig. 3. Installation for Detarring Manufactured Gas.

steam-heated compartments projecting from the shell. The raw gas enters the shell just below the header plate, passes down around the pipes and then upward through them into the top compartment to which the clean gas main is connected.

The units are energized by means of an electrical set consisting of a step-up transformer, mechanical rectifier, and control board, which operates from any ordinary low-voltage power supply. Where the capacity is large or where maximum flexibility and reliability warrant it, additional electrical sets or a spare rectifier for each transformer are normally used.

Table I shows the essentials of an operating test on a typical installation. The volume of gas was 14,500,000 cubic feet a day, or 10,070 cubic feet a minute at 60 degrees.

Specific gravity of the tar precipitated averaged 1.048. The precipitator was guaranteed to remove 95 per cent. of suspended material at rated volume of 13,270 cubic feet a minute at approximately 90 degrees F. and eight inches water suction.

This test consisted essentially of measuring the tar and water precipitated (P) for a known volume of gas, and also the suspended tar and water content (F) in the exit gas by filtration of a metered volume through a weighed filter. Both the precipitate and filter were dehydrated in order to calculate results on a dry basis. Efficiencies were calculated by the formula $\dfrac{P \times 100}{P + F}$.

In general, a detarring precipitator operates with a pressure drop of less than ¼ inch vertical water column, a power consumption of five to eight kilowatt-hours per million feet of gas, and requires only reasonable attention.

While the controlling reason for installing electrical precipitation in a particular plant may vary, it usually has its basis in some tangible or intangible economy or improvement resulting from reducing the amount of tar fog to a negligible quantity. These advantages may appear either in the equipment for recovery of ammonia, in the light-oil scrubbers, or in the purification boxes when the gas is distributed for domestic purposes. They may also result from decreased maintenance on boosters or compressors and also at the burners when the gas is used for underfiring certain makes of ovens. Frequently an increase in the amount of tar recovered and a reduction in back-

TABLE I. OPERATING TEST

Test	Date	Outlet grains per cubic foot		Inlet grains per cubic foot		Efficiency per cent.		Tar caught pounds per hour						
		Wet	Dry	Wet	Dry	Wet	Dry	Unit No. 1	Unit No. 2	L.V.	T.V.	Amps.	Tap	K.V.
	1929													
9	Dec. 20	0.324	0.0346	13.67	3.585	97.8	98.9	572	580	440	350	13.5	60	52.5
	1930													
10	Jan. 10	0.120	0.0254	10.27	3.285	98.9	99.2	376	500	445	355	13.0	60	53.2
11	Jan. 12	0.222	0.0520	9.372	2.670	97.7	98.0	339	450	443	350	13.5	60	52.5
12	Jan. 16	0.113	0.0473	11.59	4.317	99.2	99.0	477	513	448	358	12.7	60	53.7
13	Jan. 16	0.115	0.0470	12.13	4.520	99.1	99.0	495	540	445	360	12.0	60	54.0
14	Jan. 21	0.171	0.0678	10.26	3.491	98.4	98.2	450	420	442	355	12.7	60	53.3
15	Jan. 22	0.126	0.0490	9.946	3.459	98.8	98.7	432	414	445	356	12.5	60	53.4

pressure resulting in lower power consumption are very tangible economies.

REMOVAL OF FLY ASH FROM BOILER GASES

Fly ash consists essentially of glass, unburned carbon, iron oxid, and occasional unaltered mineral fragments, carbon and iron oxid being the principal variants. Ordinarily three per cent. to 25 per cent. is oversize on a 200-mesh screen, and except for size there is essentially no difference in physical or chemical characteristics between this portion and the fines. Microscopic examinations indicate that fully 50 per cent. would pass 500 mesh and, with only light grinding, probably 80 to 85 per cent. falls below 1000 mesh, most of it below 0.01 millimeter in diameter. The individual grains are mostly thin-walled spherules, bead aggregates, beads and fragments. Because of uniformity, it is improbable that any system which isolates and collects only a portion of the dust while the remainder passes through with the gases will prove satisfactory.

The need of equipment for collection of fly ash is a relatively recent one and is an outgrowth of the rapid expansion in use of powdered fuel for firing boilers. At first it was thought that the ash could be discharged with the gases, and since it apparently was valueless, this seemed the desirable thing to do. Engineers responsible for the design of power-houses were, therefore, inclined to make some general provision so that equipment could be installed, and to delay the actual installation as well as selection of the equipment itself, until operation had proved that it was necessary.

As yet there are no firmly established precedents in this matter, but it appears that ultimately a power-house, irrespective of whether it is located within municipal limits or at a point remote from thickly populated centers, will be permitted to discharge to the atmosphere only those gases which contain the lowest practical content of ash. Evidencing this, we may quote excerpts from a recent editorial in *Industrial and Engineering Chemistry* (September 1930, p. 925), where, in referring to a recent court decision in England it was stated "According to this precedent a steam plant anywhere might be held liable for nuisance or damage caused from both visible and invisible smoke" and also "Communities are certain to insist on the power plants of industries emitting only the cleanest gases from their stacks even though individual householders in the aggregate contribute more

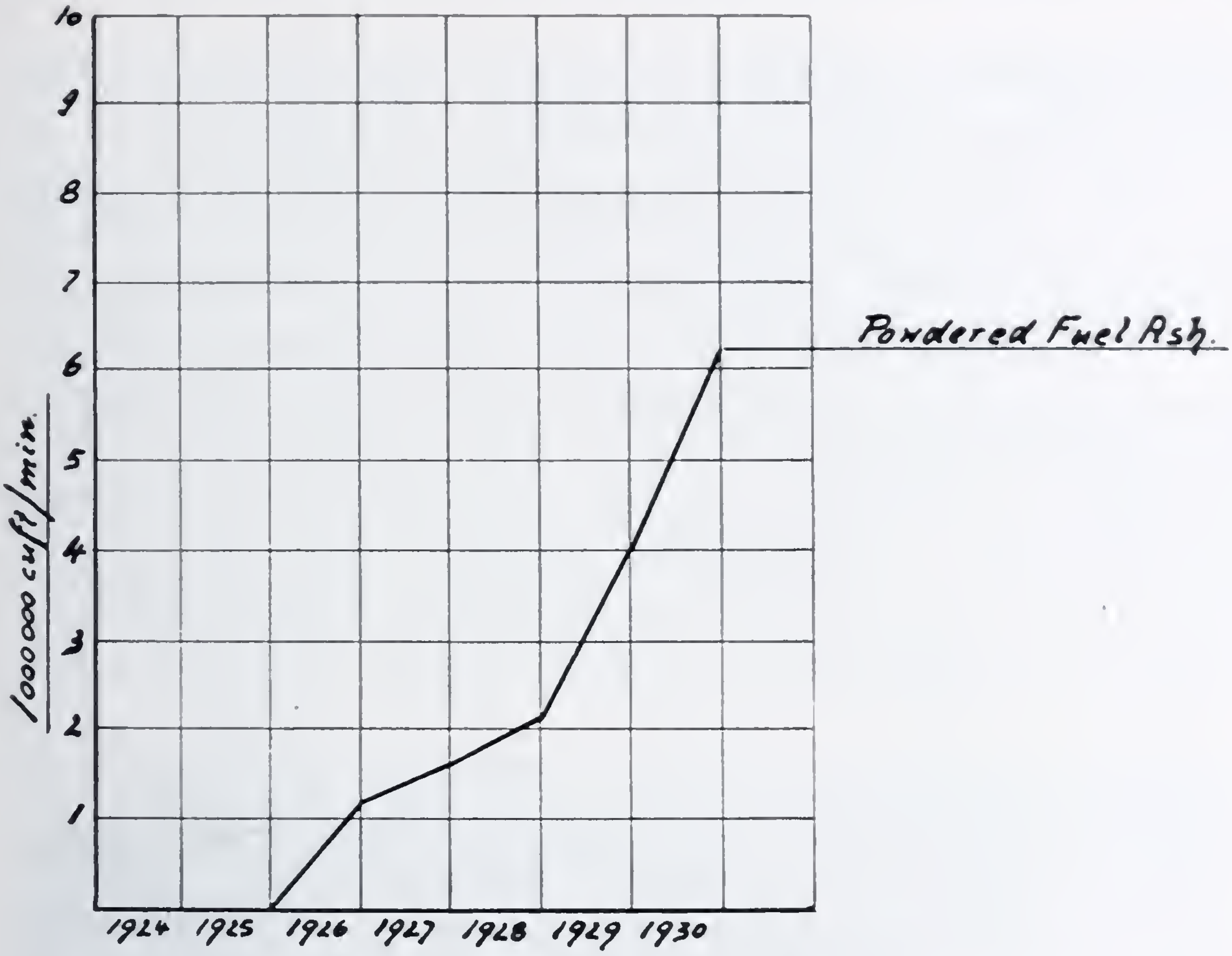

Fig. 4. Curve Showing Installed Capacity of Precipitators for Ash from Powdered Fuel.

to air pollution than all industry combined. Fly ash sulphur compounds and dust—all must ultimately be eliminated."

The yearly increase in the volume of these waste gases that are being cleaned in electrical precipitators (Fig. 4) may also be cited in evidence. It therefore appears that designs for power-houses, especially those in which the boilers are to be fired with pulverized coal, should include comprehensive lay-outs of equipment for smoke abatement even though actual construction may have to be deferred.

Electrical precipitators for collection of fly ash are usually located on the roofs of power-houses, with a single precipitator to a boiler, although this is not essential. A common location is between the induced-draft fan and the stack, although installations are being made with flues so arranged that the precipitator is ahead of the fan. It is important to locate the equipment so that the connecting flues permit a reasonably uniform distribution of the gases through the precipitator with minimum back-pressure.

Large capacity in single precipitators is essential in order that they may be fitted into the limited space that is usually available and

so that advantage may be taken of economies resulting from construction of large units rather than a multiplicity of smaller ones.

Fig. 5 shows the general construction. This design is divided into two parallel units through which the gas flows horizontally, there being a gas-tight dividing wall between them, and separate connections to inlet and outlet flues. Each unit is further divided into two sections in series, a section being a single bank of electrodes with its individual hopper and high-tension electrode system. The latter is supported from insulators mounted on the roof of the precipitator where they will not become fouled. General practice is to provide in each section 8, 10, 12 or 15 ducts in which the precipitating field is maintained by means of wire discharge electrodes suspended between

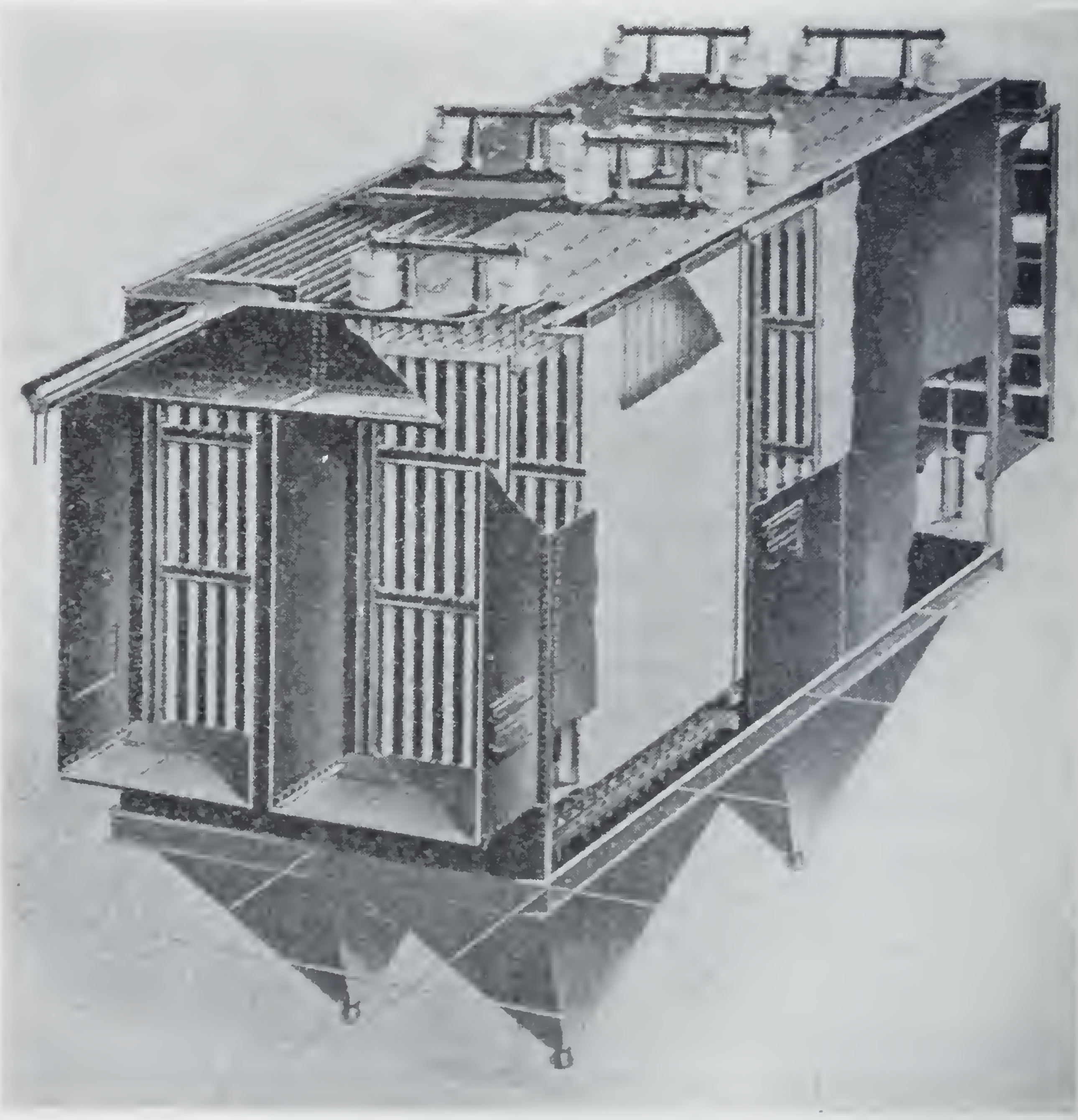

Fig. 5. Precipitator for Fly Ash from Powdered Fuel.

reinforced concrete slabs. These are the collecting electrodes. Two such ducts in series have a nominal capacity of 6000 cubic feet a minute, and since a precipitator may have as many as three units of 15 ducts each, it is apparent that a total capacity of 270,000 cubic feet a minute, which corresponds to a steam production of approximately 500,000 pounds an hour, can be built into a single precipitator.

Electrical equipment for energizing the precipitators is of the usual type. As a rule the inlet sections are connected in parallel to one electrical set, and the outlet to a second set. The electrodes are essentially self cleaning, but a pneumatically operated cleaning device is provided to remove accumulations at infrequent intervals. Control boards for the latter, as well as for the electrical equipment, and the means for disposal of the dust, are arranged so that the usual boiler-operating crew can provide the routine attention that is required. The power consumption is usually at the rate of five kilowatt-hours per 1,000,000 cubic feet of gas cleaned. Back-pressure chargeable to the precipitator is approximately 0.2 inch vertical water column at normal rating.

The appearance of gases leaving the stack gives a ready indication of the performance of dust-collecting equipment, but it is difficult to gage quantitative efficiencies in this way. A method for testing has been worked out. The basis of the test procedure is the Brady filtration method, which consists in drawing a metered volume of gas through weighed thimbles inserted in the gas stream. Depending on size and arrangement of flues, a test consists of 8 or 16 such samples at uniformly distributed points in both the inlet and the outlet flue, taken as nearly simultaneously as possible. That this method gives a reasonably accurate measure of efficiency is borne out by recent tests in which the dust, which was removed from the hopper and weighed, checked within three per cent. of the precipitated dust as calculated from the gas volume, which was in turn calculated from coal consumption and gas analysis and the dust content per cubic foot of gas as determined by test.

CLEANING OF BLAST-FURNACE GAS

The general subjects of collecting fly ash and cleaning blast-furnace gas have a point of contact in the fact that if the latter gas were used without some form of cleaning, it also would be an impor-

tant source of atmospheric pollution. However, the principal incentive for extending the practice of cleaning blast-furnace gases has been the economic side, since it has resulted in lower costs and increased efficiencies in that part of the plant and the equipment in which the gases are utilized.

Until recently, most blast-furnaces got along with primary cleaning which leaves a residual dust content of approximately 0.1 to 0.5 grain of dust per cubic foot of gas under standard conditions. Now it appears that additional savings may be obtained by substituting blast-furnace gas for other steel-mill fuels and by going to stoves with smaller checkers. When used for these purposes, however, the dust content apparently should be within the limits of 0.005 to 0.015 grain per cubic foot so that, in a large measure, the general adoption of this new practice will depend on a supply of very clean gas at reasonable cost. Since, by means of electrical precipitation, it is possible to reduce dust contents to almost any desired point simply by varying the amount of equipment that is installed, it is only natural that furnace operators should give consideration to its application in this field. Its adoption has been at relatively a slower rate than that for detarring and for the collection of fly ash, but even though it may not be the ranking method for cleaning blast-furnace gas at present, an account of its present status may be of interest.

Plant operators who have adopted electrical precipitation for this purpose have had some specific reason for doing so and it appears that these reasons may be summarized as follows:

1. To conserve in the top gases the sensible heat, which was high because of high temperature and low moisture content.
2. To compensate for shortage of water for scrubber.
3. To recover the dust in a dry state, and thus reduce the possibility of stream pollution by scrubber effluents.
4. To obtain gas sufficiently clean for use in gas-engines in a single stage following the dry dust-catchers.
5. To obtain a gas of higher cleanliness (both as regards solids and entrained water) than was being obtained with primary and secondary scrubber equipment.
6. To take advantage of low requirements for power and water.

The order in which these reasons are stated is not necessarily the order of present relative importance, but rather the arrangement is chronological in order to show how certain characteristics of electrical precipitation at one time or another have been the dominating reasons for its employment for cleaning of blast-furnace gas.

About the time that the commercial exploitation of precipitation was first being attempted, the use of primary cleaned gas in stoves and boilers was general so that the natural field appeared to be in hot dry cleaning, in order to conserve the sensible heat in the top gases, and all of the early experimental work was in this direction. There have been numerous attempts to accomplish this by other means and with other equipment and while electrical precipitation has undoubtedly proved the most satisfactory method, hot dry cleaning still stands as probably the most difficult operation in industrial gas cleaning.

In any blast-furnace the top gases will lack uniformity and the degree of irregularity will vary with different furnaces. Gas volumes, temperatures, pressures, moisture and dust contents, and the physical and chemical characteristics may change with extreme suddenness, and to be wholly successful the cleaning equipment must be sufficiently flexible to adapt itself to these irregularities whenever they occur.

The first attempts at utilization of electrical precipitation in this way indicated the existence of fundamental difficulties. Even with the most uniform gas conditions, whenever the temperature exceeded a critical point which was approximately 225 degrees F., it was difficult to obtain a cleaned gas in which the dust content was at all times less than 0.2 to 0.5 grain per cubic foot at standard conditions. The applied voltages were subnormal and current flow was abnormal for the dimensions of the electrodes which were being used. Further investigation showed that this was due to a so-called back ionization phenomenon resulting from the deposit on the collecting electrode of a heterogeneous mixture of electrical conducting and non-conducting dust particles which is characteristic of dust in most blast-furnace gases. Partially by accident it was found that these troublesome phenomena could be eliminated at any gas temperature, provided there were present in the gas certain hydrocarbon vapors; for example, those resulting from distillation of a small amount of coal added to the furnace charge. Normally the equivalent of 25 to 30 pounds of

bituminous coal per ton of iron added in batches of 500 to 600 pounds will produce the required effects, and nothing has been found to indicate that it need exceed 40 pounds.

In general, the equipment now provided for this operation is similar to that used for powdered-fuel ash and previously described, with the exception that single instead of multiple unit precipitators are used, these ordinarily having a capacity of approximately 25,000 cubic feet, and being provided in sufficient number to take care of the gas volume and give some reserve. Also, the shells are built to withstand higher gas pressures and are lined with brick. Present installed capacities for hot dry cleaning amount to 825,000 cubic feet a minute.

Experience shows that after the equipment has been adjusted for the particular furnace equipment, results both as regards gas cleanliness and reliability compare very favorably with those of a good primary scrubber. Power requirements are approximately one kilowatt-hour per 100,000 cubic feet of gas under standard conditions, but this depends to some extent on the amount of reserve capacity it is necessary to include in order to take care of the irregularities of the particular furnace for which the precipitator is built. The dust is collected dry and, depending on subsequent disposal, may either be handled in a dry state or sluiced away. The equipment can be operated with normal gas temperatures as high as 600 degrees F., but in general it is preferable that they be kept nearer 500 degrees F. Ordinarily when normal temperatures are in the neighborhood of 600 degrees F., there is a greater tendency for peak conditions under which temperatures might go considerably in excess of these. When this happens, electrical insulator failures are more frequent and this has probably been the principal operating difficulty on these installations.

The outstanding advantage of this method of treatment is that clean gas is available for stoves and boilers at a temperature of 50 to 200 degrees F. below the top temperature, depending on the location of equipment, the length of flues, and the type of heat insulation used. When the gases are at the temperatures noted and have a natural moisture content not exceeding 20 to 30 grains per cubic foot of dry gas, the sensible heat saving may approximate five per cent. of the total heat in the gas, which is an appreciable item.

To go back to the early experimental work, it was found that the back ionization effect which could be eliminated by the presence

of hydrocarbon vapors was also absent whenever the temperature of the gas entering the precipitator did not exceed the stated critical point of 225 degrees F. and that, under these conditions, raw gas could be cleaned in a single stage to a dust content of less than 0.015 grain per cubic foot under standard conditions. According to the standards at that time, this cleanliness was equivalent to that of secondary cleaned gas for use in gas-engines. It is true that a definite moisture content was required in addition to a temperature below the critical point, but this was found to occur naturally in most top gases, or else it resulted when the gases were cooled to the critical point by the evaporation of water sprayed in atomized form. Also, the dew-point corresponding to the required moisture content was sufficiently below the critical temperature to permit the collection and removal of the precipitated dust in a dry state.

It was immediately obvious that precooling would be beneficial in other ways. It would level off the irregularities in gas temperatures and gas volumes, thereby reducing the amount of reserve equipment required. There would be an actual shrinkage in volume due to temperature reduction, which could be translated into smaller and therefore less costly equipment. Also, for lake ore practice, it was found that while gas temperatures varied from 200 to 580 degrees F., and moisture contents from 17 to 61 grains, the overall averages were respectively 325 degrees F. and 39 grains. Under these conditions the saving of sensible heat does not warrant the higher initial and operating costs of hot dry cleaning. Furthermore, if these particular gases were cooled to the critical precipitating temperature by evaporation of water sprayed into them, the heat balance, by calculation, compared favorably with that for a wet scrubber system.

These developments and observations have resulted in a second method of applying electrical precipitation to cleaning of blast-furnace gas. This may be termed dry cleaning after spray cooling. At present, 11 installations employing this method have been built, all being located in Europe and all having the same general arrangement. The gases after leaving the furnace go through the dry dust-catchers and then into a tower where water is sprayed in by atomizing sprays. Approximately 50 per cent. is evaporated and converts the sensible heat into latent heat, increases the moisture content of the gases and reduces the temperatures to approximately 165 to 200 degrees F. The

gases then enter the precipitator, where the dust is precipitated in a dry state.

In these plants two distinct types of precipitators are used. One is a unit of the plate and wire type, with up-and-down flow. There are only two ducts in each pass so that the capacity of an individual unit is approximately 5000 cubic feet a minute. The required number are arranged in a battery so that an individual unit can be by-passed for cleaning the electrodes.

The other type is a pipe precipitator with upward flow, the pipes being arranged in nests to facilitate cleaning. Briefly, the operating principle is similar to that used in the Halberger-Beth system except that an electrical field instead of a filtering bag is used for removing the suspended material. Several reports* have been made on the operation of these plants and the reader is referred to these for a more detailed account. In general, dust contents are reduced to approximately 0.015 grain per cubic foot of gas under standard conditions, with a power consumption in the precipitators of approximately one kilowatt-hour per 100,000 cubic feet of gas.

Certain groups, particularly in Europe, have believed that the precipitation equipment for a blast-furnace should be designed and installed so that a cooled gas with a dust and entrained moisture content below that obtainable by any other means is produced at all times and irrespective of furnace irregularities. This has led to a third method of applying electrical precipitation to blast-furnace gas. This is accomplished by installing a precipitator to operate solely as a secondary or fine cleaner. This is preceded by a rough cleaner and cooler, which may consist either of a primary precipitator to remove the bulk of the dust in a dry state, followed by a cooler; or of a primary scrubber such as is now in common use.

Four installations have been built or are under construction using this method, the first of which has been operating for the past two years at the Hochofenwerk-Lübeck. There are three blast-furnaces, two of which operate simultaneously, and produce approximately 250 tons a day each. The ores are a mixture of approximately 70 per cent. sintered spent pyrite and 30 per cent. Swedish ore.

Somewhat more than half of the total gas is cleaned in the Cottrell plant, the remainder being taken care of by old-type Schwartz

Stahl und Eisen. 1929, v. 49, p. 1256-1261.

disintegrators and Theisens. Since it was proposed ultimately to install precipitators to handle all of the gases, the present installation is designed somewhat in excess of the load which it now carries.

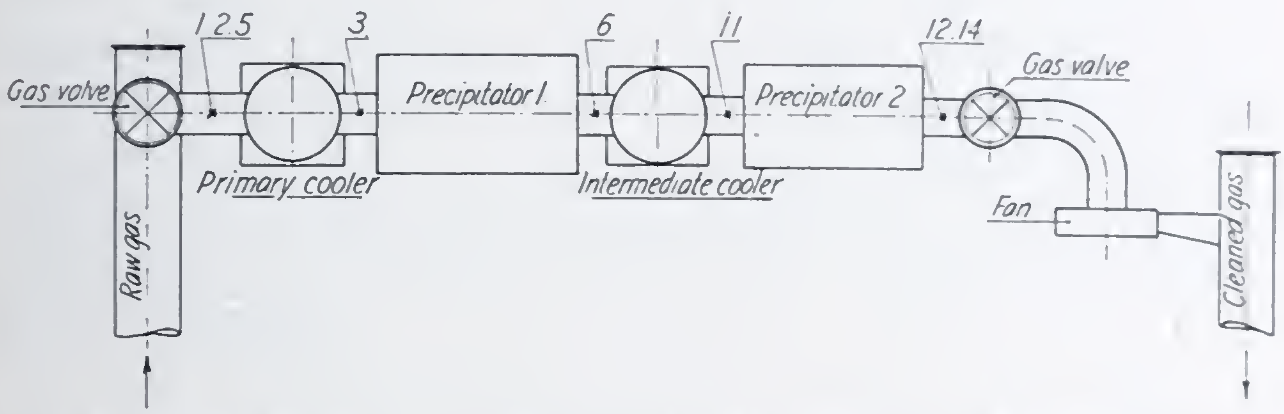

Fig. 6. Flow Sheet of Installation for Cleaning Blast-Furnace Gas.

Fig. 6 shows the general arrangement of the installation which is in two stages, each stage consisting of a cooler and a precipitator. The gases enter the top of the primary cooler, which is simply a steel tank without hurdles. Water is atomized by means of sprays at the top, and approximately 50 per cent. is evaporated so that there is relatively little overflow or dust removal in this tower. Automatic controls are provided for the water feed and also for a gas by-pass around the cooler to provide essentially a constant temperature at the precipitator inlet regardless of the raw gas temperatures.

The primary precipitator is of the horizontal-flow, plate and wire type. The shell is unlined and is of reinforced steel-plate construction. Hoppers which empty into a screw conveyor are provided under both the inlets and outlets and also under each field or section of which there are three in series. Corrugated steel sheets are used for collecting electrodes and special alloy wires for discharge electrodes. To remove deposited dust, both are rapped at intervals of approximately 30 seconds by a system mounted on top of the precipitator and driven by a single motor.

The secondary cooler is of the hurdle type. Its function is simply to cool the gases as much as possible and condense moisture. Little, if any, dust is removed, so that the effluent is clear and can be cooled and recirculated direct or run to the sewer without treatment.

The secondary precipitator removes the residual dust and any water entrainment. The precipitate is a slime, and any accumulation on the electrodes is removed by flushing for two minutes at 12-hour

intervals. This unit is also of the horizontal plate and wire type, with three sections in series. It differs from the primary precipitator in that the sections are shorter, the plates are reinforced flat sheets, and no electrode rapping device is provided.

There are four electrical sets, one of which is a spare. Two of these are used for energizing the primary precipitator while all three sections of the secondary operate in parallel on the remaining set.

To check the reliability of this plant, a test run of a week's duration was made in which all cleaning occurred in the secondary cooler and precipitator. The gases first passed through the primary cooler and precipitator, but the latter was not energized. Average test results show that when handling 35,000 cubic feet a minute the dust content was reduced from 4.3 grains to 0.01 grain per cubic foot. In this test, the secondary cooler also served as a scrubber, reducing the dust content from 4.3 grains initial to 0.8 grain at the inlet of the secondary precipitator.

The test just referred to indicates the results obtainable with a fourth method of applying electrical precipitation to blast-furnace gas—one which is particularly applicable to American plants, and especially those which now have primary scrubbers. This requires a single precipitator which would operate as a fine cleaner to remove residual dust and entrained water from the primary scrubbed gas.

An installation utilizing this method has been built at a furnace smelting lake ores. The precipitator, except for size, is essentially similar to that at Lübeck.

Operation of this installation has shown that the precipitate from this particular gas has a greater tendency to adhere to the electrodes and requires more frequent operation of the flushing sprays than is the case at Lübeck. It seemed desirable, from an operating standpoint, to eliminate flushing, if possible, or at least to reduce the frequency, and this has been the object of tests that are still in progress on a somewhat smaller precipitator. Results to date have given every indication that the latter object has been accomplished and that the capacity of an installation of given size may be increased beyond former expectations.

The principal advantage of this method is that a cool dry gas with a dust content as low as 0.005 grain per cubic foot can be obtained with a minimum amount of new equipment where primary

scrubbers are now in use. The power and water requirements, respectively, will be approximately 1.0 kilowatt-hour and 80 gallons per 100,000 cubic feet under standard conditions.

In summarizing the present status of electrical precipitation for cleaning blast-furnace gas, it may be stated that there are four distinct methods of application and that installations utilizing each method are now operating in various parts of the world. The method which will prove best for a particular plant is determined by local conditions such as possibility of heat conservation, water-supply, disposal of the dust, cleanliness of the gas that is required, and permissible operating costs.

DISCUSSION

W. P. Chandler, Jr., *Chairman:** We are certainly very much indebted to Mr. Hedberg for his very able paper. I am sure there are a number who will want to find out a little more about this subject in general. As a great many blast-furnace operators are present to-day and some of them may not be entirely familiar with the electric precipitation method, it would be of value to see how some of the other methods of gas cleaning operate in comparison with this method. One of our members has done a good deal of work investigating various types of gas-cleaning equipment and I would like to call on Mr. Flanagan to say a few words.

W. N. Flanagan:† This distinguished audience does not realize how fortunate it is. Circumstances beyond my control prevented me from preparing a discussion of this paper, so you will be spared that infliction.

There are a few points that have occurred to me as being of importance in the consideration of dust removal. My remarks will be confined to the subject of blast-furnace gas.

The first thought is the relation of value of gas to cleanliness. This point is overlooked in most accounting systems in steel-works.

Raw gas has little, if any, more value than steam coal. Partially cleaned gas has an increased value; usually the increase is several times the cost of cleaning. Well-cleaned gas may be worth from 40 to 100 per cent. more than coal, since for some purposes it may compete with

*Chief Engineer, Furnace Equipment Department, Blaw-Knox Co., Blawnox, Pa.
†Special Engineer, Carnegie Steel Co., Pittsburgh.

other fuel gases; also, clean gas enables the use of stoves that require only half of the fuel used by stoves heated with rough gas.

The second thought is the type of cleaning. Dry cleaning of hot gases, where the sensible heat may be conserved, has a big advantage, as in the case of stove and boiler gas, but presents many difficulties if a high degree of cleanliness is required. However, in blast-furnace operation particularly, one of the big factors is the recovery of the flue-dust in a usable or convertible condition. If too much of the dust is removed in wet processes a filtering operation is required to reduce the moisture content to the point where it can be mixed with dust removed from the dust-catcher and sintered. With the use of dry-cleaning methods for the bulk of the removal, there may be sufficient dry dust to mix directly with the wet sludge from the final wet washers, thus avoiding further complication and upkeep.

The third thought is the exact cleanliness required for each use. Authorities differ due to the difficulty of determining, except by a long period of trial and testing, just the cleanliness required for stoves, for long-distance transmission, or for regenerative furnaces. Stoves are being built with smaller passages, their designers anticipating still cleaner gas. The question arises as to what cleanliness is justified. In many metallurgical processes the waste gases carry more dust into the checkers than any ordinary quantity contained in the fuel gas. This one problem might be the subject of an entire meeting, but it appears that inefficient moisture removal following wet cleaners has been responsible for considerable of the striving for excessive cleanliness.

In conclusion, there are two of Mr. Hedberg's methods of cleaning for which I can see but one advantage. One is where the gas is cooled down to the critical temperature of about 225 degrees F. in the first spray tower, then partially precipitated, followed by a complete cooling in a second spray tower, and lastly passed through a second Cottrell precipitator. Why is it not cooled down, in the first tower, to the minimum temperature available with the water? Secondly, spraying water into the average blast-furnace gas will increase the moisture content so that the gas from the furnace, when it is reduced in temperature to 225 degrees, will cause as much stack loss at the boilers and stoves, due to moisture, as is gained from the 225 degrees of sensible heat. What is the gain in treating gas at 225 degrees? Why

not cool the gas down to the temperature of the available water, thereby reducing the moisture to a minimum and at the same time securing greater cleanliness; that is, the efficiency of the spray cleaner times the Cottrell efficiency. Is the purpose of the processes just mentioned to permit of maximum dust recovery in the dry state?

W. P. CHANDLER, JR., *Chairman:* We also have with us a man who has had considerable experience in operating an up-to-date wet-cleaning plant for blast-furnace gas, Mr. Unger, Superintendent of the Carrie furnaces of the Carnegie Steel Company. Will he say a few words?

W. S. UNGER:* The question of gas cleaning is one which has been receiving more and more attention since the World War. What previously had been considered gas of sufficient cleanliness is no longer satisfactory. This condition is due principally to two causes.

The first is that inhabitants of communities have felt that it is now unnecessary to endure the nuisances from certain industries, and have so expressed themselves by direct complaints, by representative civic organizations, by injunctions, and by suits for damages. The other cause contributing to better gas cleaning has been the progress, due to investigation and experience, in the manufacture of cleaning equipment, which in turn has been passed on to the trade, thus causing dissatisfaction with the old order of things and a desire for the newer and better methods. This is especially true in regard to the cleaning of blast-furnace gas. The blast-furnace operator has witnessed the coming of the Feld type of washer in place of the older tower or baffle washer; the disintegrator in place of the older Theisen washer; the centrifugal dry cleaner which takes most of the load off the primary washer and at the same time collects the dust in the dry state; the filter which collects the valuable dust from the wash water, and the Cottrell precipitator which replaces the drum-type Theisen as a final cleaner.

It seems that three fairly well defined lines of thought are developing in American practice. The first school believes in passing the gas after its exit from the primary dust-catcher through some centrifugal or impinging cleaner, thence into a Feld washer, and from there through a disintegrator and water eliminator. Approximately 50 to

*Superintendent, Carrie Furnaces, Carnegie Steel Co., Rankin, Pa.

60 per cent. of the Feld washing water is by-passed directly to the sewer, it being sufficiently clear so that no stream pollution results. The remaining portion is thickened by means of some type of thickener such as the Dorr, from which it is used to mix with the dry dust collected from the dust-catcher and centrifugal dry cleaners to form a mixture containing not over 12 per cent. moisture. The second school passes the gas after its exit from the dust-catcher through a tower or spray washer, thence through a disintegrator and water eliminator. The washing water is collected, thickened, and then filtered. The filter cake is then dumped upon the dry dust collected from the dust-catcher. The third school follows the same procedure as the second school except that a Cottrell precipitator is used as a final cleaner in place of the disintegrator and water eliminator. It is our belief that the use of the precipitator alone is not being looked upon with as much favor as it was formerly, principally on account of its inability to cope successfully with variations in gas flow such as exist during a furnace slip.

In order to obtain a comparative cost of installation for these three systems, certain basic assumptions are necessary. It will be assumed that it will be necessary to clean all the gas from a blast-furnace producing approximately 3,500,000 cubic feet of gas per hour at standard conditions. Part of this gas will be used in gas-engines. The excess will be used in small checker stoves and for oven heating in the coke works.

The ground upon which each system is built is assumed to be owned by the plant proper. This ground is also assumed to be able to withstand a loading of two net tons per square foot, and to consist of a slag, brickbat, and refuse fill such as is encountered in the ordinary mill yard. Also, it is assumed that no piling will be used, as the bearing area of the foundations will be made sufficient to withstand the loadings imposed. All gas mains carrying hot gas will be lined with 4½ inches of brick. The mains will be so designed that the velocity in them will be less than half a mile a minute. All water lines, with the necessary circuit-breakers, safety switches, etc. Sewers will valves, fittings, etc., are to be cast-iron capable of withstanding 125 pounds water pressure. All electric wiring is to be carried in conduits be provided to carry the waste water away. All equipment is designed to withstand a gas pressure of 25 pounds per square inch.

Automatic goggle valves will be provided where necessary. In all cases adequate spares will be provided and charged against the investment. A comparison is shown in Table II. There is no power charge for pumping, as water is assumed to be of sufficient head in all cases.

TABLE II. COMPARISON OF THREE SYSTEMS OF DUST REMOVAL

	1	2	3
Centrifugal cleaner, including foundation supports for cleaner and gas main, overhead sludge tank, sludge piping, pug-mills, motors and starters, platforms, railings and steps. Manually operated goggle valves at the inlet and outlet of each cleaner	$ 65,000		
Feld type washer, including foundation, piping, spare motor drive and starter, indicating and recording instruments, shelter house over top of washer with monorail hoist. Platforms and steps. Automatic goggle valve at exit of washer	112,000		
Tower or spray washer, with same equipment as for Feld washer, except shelter house on top of washer		$ 75,000	$ 75,000
Double-tray Dorr thickener, including concrete covering, removal pump, two-pressure sludge pumps, drive, etc., with brick shelter house	31,000	31,000	31,000
Two drum filters, including drives, exhausters, belt conveyors, air-pumps, etc., in brick and galvanized-sheet building		40,000	40,000
Three disintegrators, each with capacity of 40,000 cubic feet, including foundations, motors and starters, water eliminators, automatic goggle valves and inlet and exit from each machine, all gas and water piping, in brick and galvanized-sheet building	100,000	100,000	
Three Cottrell precipitators, with capacity of 40,000 cubic feet, including all electric equipment, water and gas lines. Automatic goggle valves at inlet and exit of each cleaner. Brick and galvanized-sheet building over electric equipment			180,000
Total investment	$308,000	$246,000	$326,000
Consumption per hour			
Power in kilowatt-hours	753	725	160
Water in gallons	78,500	150,000	150,000

W. P. Chandler, Jr., *Chairman:* Mr. Unger's discussion is certainly a very fine treatment of the subject. The straight comparison of installation costs is of great value. However, it should be borne in mind that local conditions such as water-supply and power costs, may have considerable influence. I am going to ask Mr. Nesbit to discuss the paper at this time. He has done a considerable amount of work along this line.

A. F. Nesbit:* The question of freeing gases from their entrained solid and liquid particles always arouses interest among men whose labors are associated with the practice of chemical, metallurgical, and other processes, where fumes and fogs are evolved.

The problem of recovering fly ash from combustion gases of powdered coal is one of rather recent date and is a running mate with that of ash, carbon, and cinders from power-plant flue-gases on their way to the atmosphere.

It would be interesting to know what are the principal factors that have so long delayed the more extensive adoption of the electrical precipitation method of cleaning gases.

May not some of the causes be found among one or more of the following—(1) high first cost; (2) high operating cost; (3) high upkeep; (4) the element of danger attendant upon the use of high voltages; (5) the difficulties associated with the present types of precipitators which necessitate frequent alterations or repairs and the cleaning of electrodes, for either of which shut-downs are necessary, thus giving rise to interrupted service, unless a duplication of units is available; (6) lack of standardization of apparatus; or (7) may it be that the entire field of investigation is still hovering in the experimental stage? I ask these questions in all seriousness, as there must be an answer forthcoming some time and from some source. Perhaps some of those who have been approached to adopt the method for the solution of their problems will enlighten me on this subject.

Mr. Hedberg's paper still leaves my inquiries as to these factors unanswered. I firmly believe, and have often given expression to the idea, that mutually co-operative action by steel and other companies "pooling" their interests and finds for the solution of each of their common problems would get the most satisfactory results, even though it took five years to do so. Furthermore, there would be an

*Consulting Engineer, Pittsburgh.

end to duplication of effort and expense, such as is well known history in any field we might mention. This is a vital question and the adoption of such a plan for investigation would be strenuously opposed by all parties who would be competitively affected, and it is quite likely that the Sherman Act would be called upon to unscramble such a new and modern merger.

We can no longer expect any one to extend us any sympathy when we attempt to explain away our failure to get results by placing the blame on some unseen fundamental condition, chemical or physical, which, after these many years still continues to baffle us.

Electrical precipitation apparatus must either come up to the standards required for its adoption in any specific case or else it might as well cease to eixst as an exploited method of cleaning gases. I firmly believe that it has possibilities, and my faith in what may be accomplished has never weakened.

The part assigned me to-day is to place on record some information in regard to the McGee type of centrifugal gas cleaner with which I have made many tests on blast-furnace and other dusts, as well as on tar recovery and air drying, and as a heat economizer. This apparatus was developed in our search to make electrical precipitators of the pipe type continuous in their operation.

The purpose of the tests with the McGee cleaner was to secure data in regard to its fitness to operate under high and varying temperatures and pressures as experienced in blast-furnace gas mains, to be as as nearly fool-proof as possible in all respects, and to need no attention.

This type of apparatus, as shown by the full lines in Fig. 7 and in Fig. 8 for a single pipe unit shows the structural features and makes evident the principles of operation. In Fig. 7, the gas with its entrained dust passes through the duct 1 into the chamber 2, thence in a relatively small radially deep annular stream down through the space between the inner wall of pipe 3 and the centrifugal head 4. The gas is thus thrown into a high-velocity, swirling sheet along the stream boundary line by means of the vanes 5, and the centrifugal force combined with the forward velocity makes it possible to entrap solid and liquid particles in the annular gap 6, between the co-axial elements 3 and 7. The gas, freed of its entrained particles of dust or liquid, passes out through the duct 8.

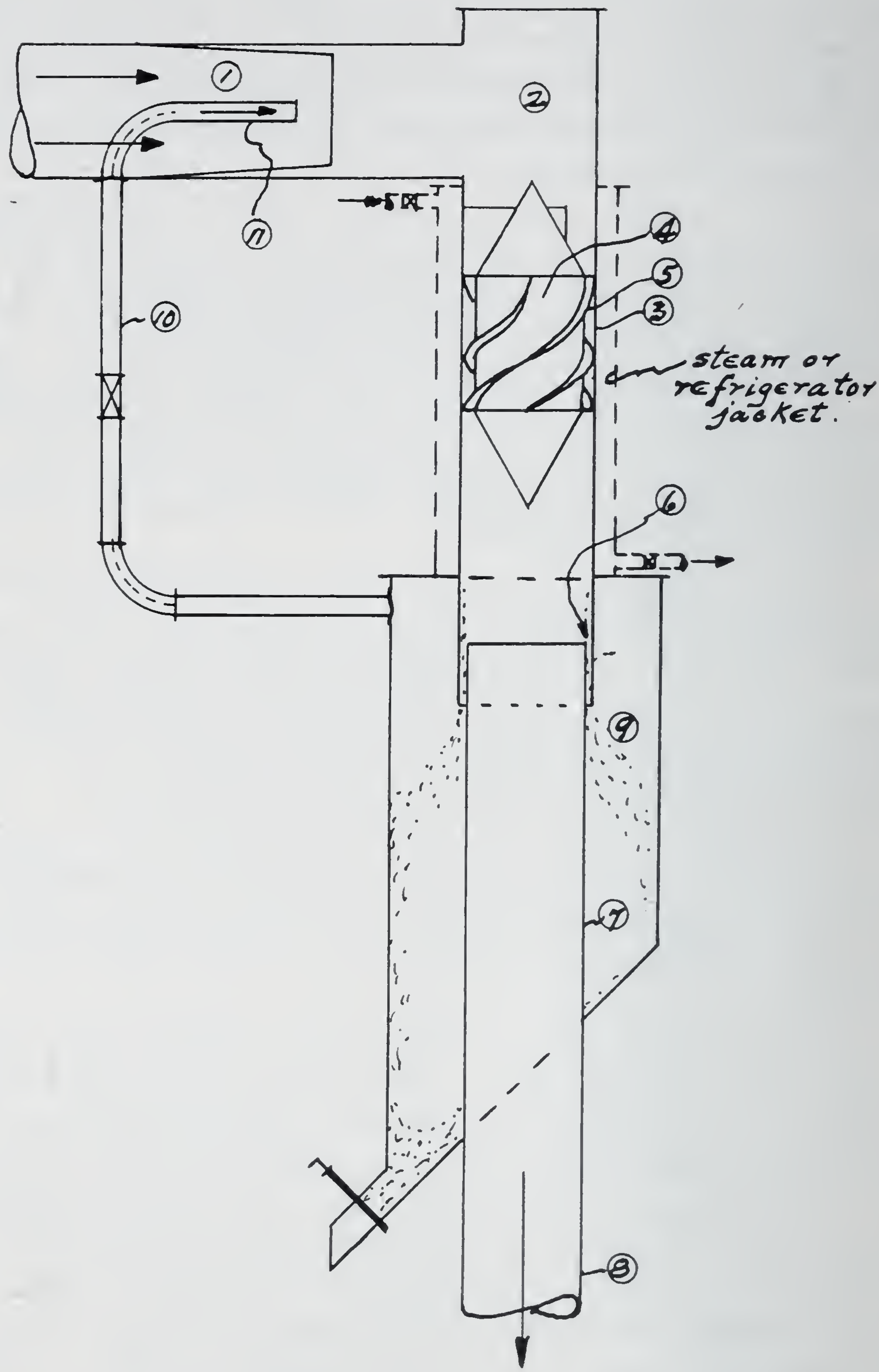

Fig. 7. McGee Cleaner.

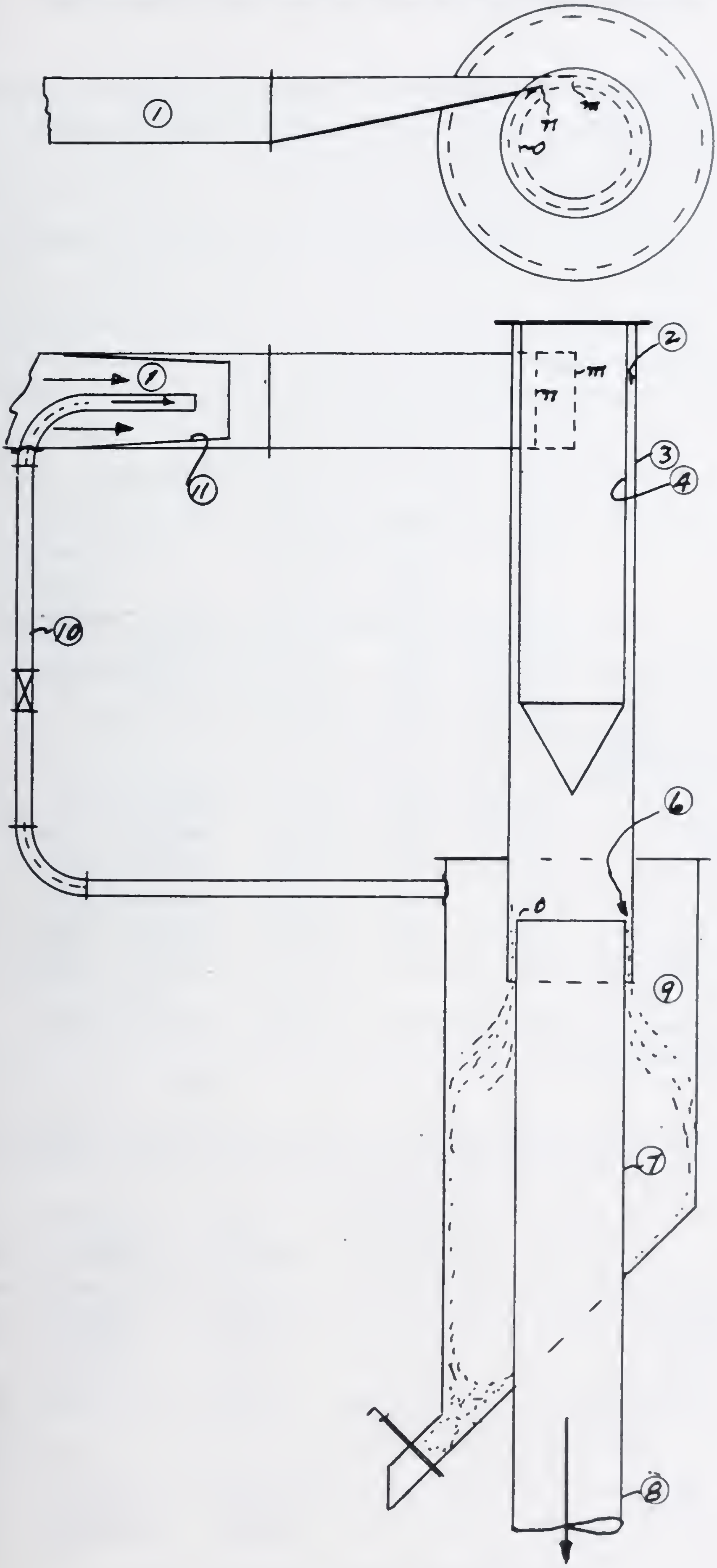

Fig. 8. McGee Cleaner without Vanes.

The dust-collecting chamber is of ample dimensions, and has a positively operating pressure-relief duct 10, which co-operates with the aspirator element 11, or its equivalent.

In the tests on cleaning of blast-furnace gas and the tests made by Mr. Boothman, to both of which I refer, the pressure-relief system was not used.

The only difference between Fig. 7 and Fig. 8 is that in Fig. 8 the gas enters a tangential duct 1 and is constrained by the vaneless cylindrical element 4 from radial inward expansion until it has

TABLE III. TESTS OF McGEE CLEANER

Test	Dust used	Volume of air discharged in cubic feet per minute	Initial concentration in grains per cubic foot	Final concentration in grains per cubic foot	Efficiency per cent.	Back pressure inches of water	Horsepower
3	Black press cake	940	9.96	1.124	88.7	3	0.87
4	Cyclone collector ore..........	940	10.05	0.73	92.73	3	0.87
17	Ore dust.......	854	8.85	0.283	96.84	2.98	0.39
24	Coke dust......	1150	1.96	0.13	93.34	3.8	1.16
26	Raymond mill...	770	7.55	0.425	94.4	4.4	0.89
27	Coke ore dust...	788	1.96	0.13	93.34	4.4	0.91
28	Raymond mill...	1500	5.15	0.339	93.45	3.25	1.28
31	Blast-furnace fine flue-dust.....	1559	5.2	0.121	97.49	....	....
32	Blast-furnace fine flue-dust.....	1193	27.8	1.91	89.1	....	....

TABLE IV. FINENESS OF DUST USED IN COLLECTOR TESTS

	Passing 200-mesh screen	First fraction	Second fraction	Third fraction
Black press cake............	94.9%	49.59%	30.56%	14.75%
Size in inches................	....	0.0029	0.0017	0.0028
Cyclone collector............	93.5%	32.04%	36.04%	25.34%
Size in inches................	....	0.00032	0.0017	0.0028
Raymond mill carbon........	53.28%	31.05%	11.72%	10.51%
		on	on	through 200
Ball mill carbon.............		100 mesh	200 mesh	mesh
		58.82%	21.94%	18.46%

acquired the desired stream path to throw its entrained dust effectively against the stream boundary line. The figures have like operating parts similarly numbered, and otherwise their actions are readily understood.

In these two figures it will be recognized that large centrifugal forces are brought into action, compared with the well known cyclone type of dust collectors.

The centrifugal force on any particle of weight, W, making N revolutions per second in a pipe of internal diameter, D, may be expressed in time of a constant, K, as $F = K D N^2 W$.

Tables III and IV refer to results by Dale M. Boothman, of the Aluminum Company of America, with a single unit McGee type of cleaner as shown in Fig. 8, the inner element, 4, however, being omitted.

In test 32 there was considerable loss at the eye of the fan.

The percentage of efficiency is the actual weight recovered.

Coke dust used in test 24 all passed through a 200-mesh screen.

The tests up to and including 27 were all made on units 12 inches in diameter. Tests 28-32 were made on units 18 inches in diameter. We consider for commercial installation, considering gas velocity and efficiency, that eight inches in diameter would be the proper size. Power to deposit dust with units eight inches in diameter would be 1½ times the power of a 12-inch unit, and 2¼ times the power of 18-inch units, with the same initial gas velocity. Units can be assembled in compact formation; for instance, to handle 100,000 cubic feet of gas per minute would require an outside shell diameter of only 16 feet.

It will be noted that in the McGee cleaner the escaping clean gas, after it has discharged its entrained dust, travels forward in the same direction as it was traveling during the process of throwing the dust against the stream boundary line. It will be further noted that the pressure-relief system, operating jointly with the dust-collecting chamber, necessarily recirculates a portion of the gas entering chamber 2.

With the McGee cleaner shown in Fig. 7, without the pressure-relief system, the writer has made many tests on dust and cement dust, with results that are in every way as attractive as those obtained by Mr. Boothman.

Tests have also been made by the writer, with and without the pressure-relief system, in connection with detarring gases, the removal of water and oils from gases leaving spray towers, and the use of such a unit as a possible waste-heat boiler or economizer. In these cases the jacket shown in the dotted line in Fig. 7 was used.

The results have been attractive, and recent inquiries may lead to the use of a multiple grouping of such units to serve as a means of tar extraction and by-product recovery in successive stages.

Mr. McGee tells me that a group of units, similar to that shown in Fig. 7, was designed to clean blast-furnace gas for use as a fuel for two boilers. Only one boiler, however, was connected to this cleaner, and it therefore operated at a low efficiency (about 60 per cent.) but was in continuous service day and night for 13 months without any attention except to remove the collected dust. The wear shown on easily replaceable parts at the end of 13 months was less than anticipated.

The chief disadvantage in connection with the use of the cleaner shown in Fig. 7 is the back-pressure in the chamber 2.

It is quite likely that more will be heard about the McGee type of centrifugal gas cleaner in the near future.

W. P. Chandler, Jr., *Chairman:* One question brought up by Mr. Nesbit I think might well be discussed at this time. He mentioned the dust content of the blast-furnace gas in Birmingham as compared with that of the Pittsburgh district. The dust content of one furnace might vary considerably from the dust content of another in the same district. We have with us this afternoon a gentleman who has been experimenting quite a good deal along the line of reducing the dust content of the gas before it leaves the furnace at all. I am going to ask Mr. Riddle to say a few words.

L. E. Riddle:* You can readily see from what Mr. Unger told you that regardless of how successful we are with wet washing and with our various washers, disintegrators, etc., we are able to make blast-furnace gas cleaner than the normal atmosphere, but at a cost which we would like to see reduced. The cost of cleaning has, therefore, left the field wide open for different kinds and types of cleaners.

*General Superintendent, Isabella Furnaces, Carnegie Steel Co., Etna, Pa.

The first time I ever heard of electric precipitation, and that was a good many years ago, Professor Nesbit came from the University of Pittsburgh to our plant and talked about precipitating dust before it left the furnace, and later on Dr. Cottrell, of the Research Corporation, came along with high hopes for successful and cheap electric precipitation. The advancement has been slow, but I still believe electric precipitation will get somewhere some day and get the results accomplished by wet washing.

In speaking about the wet washer, one of the things Mr. Unger mentioned was the sludge. That is always objectionable in handling and dewatering. The dry dust is not so objectionable and is easier to handle and convert into sinter, but it is expensive to lose any part of it and costly to put into condition for use. Therefore, it has long been a study with us how to decrease the amount of flue-dust produced, and your Chairman has asked me to speak of this phase of the gas problem and not discuss Mr. Hedberg's paper.

During the past 15 years there has been a decided change in blast-furnace design which has resulted in enormous pig-iron production and marked economies in operating costs. This great improvement has been largely due to increasing the hearth and bosh diameters of our furnaces, permitting a larger volume of air to be blown. Practically all superintendents, at each relining or reconstruction, have increased the size of their furnaces at the bottom. Fifteen years ago, 16 feet was a large hearth diameter, while to-day 25 to 28 feet is considered good design, giving 2½ times the hearth area of the old furnaces. During all of this time it was considered necessary to maintain the old top dimensions. In other words, up until fifteen or sixteen years ago we frequently had tops slightly greater in diameter than the hearths, while to-day with the development of the large hearths we frequently have tops of only about one-third to one-half the area of the bottoms.

The result has been that while we obtained the advantages enumerated above—high tonnage and low cost for labor, with fairly good fuel consumption—our flue-dust production and our ore consumption have greatly increased. This means large sintering plants with the well known expense and difficulties of handling the flue-dust and washer sludge, and it has meant heavier burdens on our gas-cleaning equipment.

The reason for this flue-dust production is simple, although it was entirely lost sight of for a long period. On the large furnaces we blow greater volumes of air and consequently have greater volumes of gas passing through the stock columns and tops. This increase in volume of course gave a corresponding increase in gas velocity and a greater dust-carrying capacity.

The increase in gas velocity in any given furnace is of course directly proportional to the increase in gas volume, and with a furnace receiving 70,000 cubic feet of blast per minute we have a much greater dust-carrying capacity than in the old days with 40,000 cubic feet of blast, and in many furnace plants this large increase of wind blown was made with little or no increase in stock line area of furnaces.

It seemed to me that the logical way to reduce flue-dust production was to reduce gas velocity in the region of the furnace where the dust was picked up and carried out, and it also seemed that the way to accomplish this was to increase the cross-sectional area of the furnace top at the upper part of the stock column, and not only above it as had been done with locomotive-type tops and others.

For years engineers and operators concentrated on the idea of decreasing the velocity of gas passing through offtakes. They increased the number of offtakes from one to four and enlarged the cross-sectional area of each offtake with the idea of slowing up the gas and dropping the dust back into the furnace. They also made use of baffles and high uptakes.

During the latter part of the World War I had an opportunity to operate a furnace which had not been in blast for six years. It was obsolete, compared with some of the others I was operating at the time. Blowing the amount of air required to make ample tonnage on this size of furnace, we soon learned that we made less dust on this furnace than on any of the other furnaces in our group. As this furnace had but one downcomer or outlet for the gas, as against four on some of the others, and according to the theory that we all believed about dust prevention, it should have made more dust, and I began to look for the reason. The hearth of this furnace was 13 feet, six inches in diameter, and the stock line was 16 feet in diameter. At all the other furnaces we were then operating, the stock line diameter was equal to or greater than the hearth diameter. It was then that I

began to think about the larger top area greatly reducing the velocity of the gas passing through the top of the stock column and thereby reducing its dust-carrying power. As we had no occasion to build a new furnace shell, and as none of the furnaces which I relined would permit widening out the top, due to the fact that the size of the shell would not permit us to have sufficient brickwork in the top, I was unable to put this theory in practice until we redesigned the top of our furnace No. 4 at Duquesne.

In 1928 it was decided at Duquesne to reline a furnace with a much greater stock line diameter than had ever before been constructed, the shell being large enough to permit us to do this. Our No. 4 was about to be relined and, in spite of much adverse opinion on the part of experienced operators, we designed and built a 19-foot top with a 14-foot bell. The annular space between the large bell and the inwall was 2½ feet instead of the usual two feet. The inwall batter was only 23/32 inch per foot. In other respects there was nothing unusual in the design. The hearth was 20 feet, six inches in diameter, the bosh 24 feet, six inches, the bosh angle 80 degrees, and the height 91 feet, 11 inches from tapping hole to closed bell.

From the time of blowing in on March 20, 1929, to the present, the furnace has had a record of unusually satisfactory operation. The chief aim of this design—reduction of flue-dust—has been accomplished in a way which has exceeded our expectations.

Our practice for September 1930 as set forth below is typical of what is being done from month to month.

Daily average product	712.7	tons
Coke per ton of iron (net)	1924	pounds
Limestone per ton of iron	766	pounds
Ore per ton of iron	3674	pounds
Net metallic materials per ton	4297	pounds
Average blast per minute	49,600	cubic feet
Average blast temperature	1136	degrees
Average top temperature	329	degrees
Theoretical yield	52.62	per cent.
Actual yield	52.45	per cent.
Yield loss	0.17	per cent.
Mesabi ore used	90.63	per cent.
Flue-dust produced per ton of product	53	pounds

We figure the flue-dust produced to represent an 80 per cent. recovery. The reason for giving these figures is to bring out the fact that we are making a large tonnage on this size of furnace, blowing ample wind; there is no slow blowing, which is sometimes done to reduce flue-dust production.

After this furnace with the 19-foot top was designed, but before it was in blast, two furnaces at Fairfield, Ala., were built. They had been designed with 17-foot tops. Following my suggestion, after discussion at Fairfield, they changed one of these from a 17-foot to a 19-foot stock line, and this furnace was blown in a few months before our Duquesne No. 4. The dust produced with the larger top was much less than on the companion furnace.

No. 1 furnace at Duquesne followed No. 4 furnace with a 19-foot top and a 13-foot bell. Thus we had an annular space of three feet—a radical change from the two-foot annular space which for so many years had been considered essential to good furnace practice. The furnace operated for 11 months with satisfactory results and we then changed the bell to a 14-foot diameter, similar to the one in No. 4 furnace. This was done to see if any improvement in practice would result. The furnace made about the same amount of flue-dust with the smaller bell as with the larger one. The coke consumption was slightly improved and top temperatures slightly reduced. Generally the results were the same. This was interesting to us, as poor work on some individual furnaces has often been blamed on some slight deviation from the conventional design of top.

Results on these furnaces were so satisfactory that we shut down furnaces No. 2 and No. 3 and removed the stock line protection rings and with pneumatic tools cut the brick to give us enlarged top diameters. No. 3 was 17 feet and was changed to 20 feet, four inches at the top, and to 18 feet, six inches at a point 27 feet from the top. No. 2, which was 16 feet, was cut to 18 feet, three inches. This dimension was the same from the top to about 24 feet down, a longer straight throat than we would put in if we were installing a new lining.

On furnace No. 3 the results were very good. Previous to enlarging the top in March 1930, flue-dust production was 268 pounds per ton of iron. During the last three months the flue-dust has been 138 pounds per ton of iron. After cutting out the brickwork on No. 3

we used the same bell and hopper on the 20-foot top that we had on the 17-foot top, with an annular space of 3½ feet. We made good iron, had smooth operation, and had little dust. After three months we put in a bell 14 feet, six inches in diameter with the old hopper, and got equally good results with an annular space of two feet, nine inches. This furnace with but a 19-foot hearth this month has averaged 734 tons a day on 1844 pounds gross coke.

No. 2 furnace had made 820,000 tons of iron. The flue-dust had averaged 269 pounds per ton of iron; the last month before the change 315 pounds per ton of iron. Blowing about the same wind, flue-dust was reduced to 157 pounds per ton for a month. The average for the past five months has been 171 pounds per ton of iron, or a reduction of 49 per cent. The flue-dust practice had been so bad that we contemplated putting the furnace out, but the improvement was so marked that we are still operating 11 months after making the change.

A large number of dust determinations have been made on gas leaving the dust-catchers, and these show a surprisingly small quantity of dust in the gas. For many months the dust content of the gas leaving the dust-catchers on No. 4 furnace has averaged below one grain. This is interesting because records show that dust in gas after dust-catchers frequently runs from five to 15 grains. Duquesne used to run nine grains after the dust-catchers.

Our No. 4 furnace is one of the smoothest operating furnaces I have ever known in spite of 23/32-inch batter on the inwall. In No. 1 furnace the batter is 13/32 inch. The general opinion is that a batter of 1¼ inches on the inwall is almost a necessity for good work. We went to the lower batter because our furnace shells would not permit us to widen the top and have greater batter than we have. We did not find this batter harmful, and in order to get a 20-foot stock line in our No. 5 furnace the batter is but 29/64 inch.

I believe that the large furnaces with 25-foot hearths will go considerably beyond 20 feet in diameter of top. This will necessitate some new form of distribution, because the largest bell now made (14 feet, eight inches) has just about reached the limit for transportation and shop work. We do not know yet what the limit is on the size of furnace tops, but if given the opportunity to build a furnace with 27-foot hearth, I should want not less than a 25-foot top.

Increasing the stock line area in relation to the hearth is not a cure for bad furnace practice, and excessive flue-dust may still be made, but the large stock line areas together with smooth operation give decidedly satisfactory results.

T. J. Barry:* I should like to raise a question regarding the dust determination using the thimble method. Would it not pay to use a method which would handle a larger volume of air or gas, particularly where the dust loading of the gas is very low? I believe the thimble method would be open to error in a great many ways unless you have a very expert operator.

W. J. McGurty:† In testing for suspended solids in gases it is absolutely essential that the velocity be maintained in the sampling apparatus exactly as it exists in the gas main at the point of sampling. The German method of testing differs from ours, and test tabulations that I have reviewed would indicate that the velocity requirements were not maintained.

A dust content of 0.00015 grain per cubic foot would mean a ratio of one grain to 3,700,000, and in my opinion there is no testing equipment in existence that is delicate enough to detect such quantities, even if the human element were infallible.

In my opinion, rather arbitrary and stringent standards that have been set up for gas quality requirements for gas-engines, etc., have been responsible for unnecessary and excessive cleaning costs in attempting to obtain such quality.

John H. Blair:‡ My discussion will be confined to dust elimination from boiler gases, as this is the only feature in which the Duquesne Light Company is interested.

So far the Duquesne Light Company has not had any experience with electrical precipitation of fly ash from boiler gases. We expect shortly to have that experience, as we are now installing a Cottrell precipitator on one pulverized-fuel boiler at our Colfax plant.

We have made a number of investigations of various methods of dust removal from boiler gases and so far find the Cottrell precipitator gives a very high percentage of dust recovery; however, from

*Manufacturers' Representative, Pittsburgh.
†Pittsburgh Representative, Bartlett-Hayward Co., Pittsburgh.
‡Mechanical and Mining Engineer, Duquesne Light Co., Pittsburgh.

our findings, I can not say that this method is anywhere near perfected, as we find a great many troubles in the installation and operation.

There seem to be two vital points which greatly affect the successful operation of the Cottrell apparatus. One is in the operation of the concrete electrode scrapers. The working of the air cylinder for operating the scrapers is very unsatisfactory. The air pressure will first build up in the cylinder until it is sufficient to overcome friction and move the scrapers, then the piston will jump and if any of the scrapers have caught on anything the power is sufficient to break them and they fall across the electrodes, giving a short circuit and putting that particular section of the eliminator out of service until the boiler can be shut down or the gases by-passed (if such provision has been made in the original installation) and the trouble cleared up. This trouble is quite frequent, and if provision for by-passing the gases has not been made in the original installation it will cause a great deal of operating trouble and expense. However, the manufacturer claims that the electrodes are self-cleaning; if so, why the cleaners? A hydraulic-cylinder mechanism in place of the air cylinder would give more even and uniform operation and possibly solve this trouble.

Another point affecting the percentage of dust recovery is the velocity of the flue-gases through the eliminator. One company that has been operating a number of Cottrell precipitators for several years has found after numerous experiments that the best velocity of the flue-gases through the precipitator chamber is four feet per second for normal rating, with an increase to eight feet per second for maximum rating. I note that the manufacture recommends higher ratings. This is probably to keep down the size of the precipitator chamber for large volumes of gases. The lower velocities of the gases will greatly assist the large particles to settle out of the gases, as these large particles are not readily precipitated by the electrical field like the particles of fly ash.

There are a number of minor difficulties, usually local, and after considerable experimental work these are gradually ironed out, but they cause considerable operating trouble.

Regarding the proper size of downcomer pipe for the collected dust, ten inches to twelve inches in diameter seemed the most successful. Methods of emptying this dust into the ash sluice have received

much attention. One company tried to empty the dust directly from the downcomer pipe into the ash sluiceway by letting the downcomer extend into the sluiceway, but the pipe soon became stopped up on account of the capillary action—the dust causing the water to travel up the downcomer pipe some ninety to one hundred feet, completely closing up the pipe. Another company experimented with a spray chamber at the bottom of the downcomer passing the dust through numerous water sprays in a chamber some two to three feet square by four or five feet high before it goes into the sluiceway. Another company solved this problem quite successfully by inserting in the downcomer line, about eight or ten feet from the bottom, a dry-dust bin some four or five feet square by five or six feet high with a valve at the bottom, thus catching the dry dust at this point and periodically emptying this bin into the sluiceway. In case of clogging of the pipe below the bin, this short section of pipe can be removed if necessary and cleaned out.

One of the greatest unsolved problems in connection with the handling of flue-dust is what to do with the dust after it has been recovered. This fine dust requires a great deal of water to wet it down properly, and after it has been thoroughly saturated with water it requires large settling basins to precipitate or settle out. It is easily pumped, together with the ashes and clinkers, and will stay placed as long as it is kept moist, but as soon as it becomes dry the wind will drive it around, creating a nuisance. This dust can not be discharged into streams, rivers, or lakes as it will soon become a nuisance. One company has carried on various experiments trying to find a means of using this dust in road materials, furnace linings, brick, etc., but so far without any success.

One of the points in which I was especially interested was in regard to a critical temperature in the boiler gases where they have to use water sprays or precooling in the gases, to the eliminator, for successful operation in connection with precipitation of dust from blast-furnaces. In other words, can we successfully use the Cottrell apparatus in any gas temperature for either pulverized fuel or stoker-fired boilers up to as high a temperature as the concrete electrodes will stand without introducing a water spray in the gases to the eliminator? If sprays are used, then would we not have to use an acid-resisting lining in the eliminator, breeching, and stack?

C. W. Hedberg: No standard method for determination of dust contents has been generally accepted by interested groups. Usually gas cleanliness is stated without reference to the method or means by which it was determined. One who is familiar with the possible errors in determination which may result from careless or faulty technique, particularly when dealing with low contents, generally questions such results and rightfully so, unless methods and supporting data are also given.

While proving up guarantees on a Cottrell installation in New York, I personally experienced the difficulties involved in actual determinations of low dust contents order. The installation was guaranteed to remove 90 per cent. of the dust content in ventilating air carrying initially from 0.002 to 0.007 grain per cubic foot. The cleaned gas contained, therefore, approximately 0.0002 to 0.0007 grain per cubic foot. The Brady method was used and a sample of from 700 to 1000 cubic feet of gas was drawn through each thimble. This gave an increase in weight of from 0.01 to 0.05 grain which was weighable. Careful drying and weighing of the thimbles was necessary and, even with extreme care there were one or two determinations in which the thimble used in the cleaned gas weighed less after the filtration than before.

As a general statement, it is believed that under favorable conditions the Brady method will show accurate determinations down to 0.005 to 0.001 grain per cubic foot, and I personally would not vouch for the accuracy of results lower than that unless extreme care is exercised.

While on the subject of sampling we might also cover the question with reference to the use of bags or larger exhaust units for sampling, instead of the thimbles as used in the Brady method which handle at most only a few cubic feet a minute. The ideal method for determining the effectiveness of gas-cleaning equipment is probably that in which all of the gas, after leaving the unit under test, passes into a bag or other equipment in which all of the remaining dust or suspended matter is easily collected and weighed. Obviously such a method is impracticable except in the case of small volumes of gas. When the equipment under test has a capacity of approximately 200,000 cubic feet of gas per minute, a sample amounting to one per cent. would be so large that the equipment for handling it would be unwieldy.

Accuracy in testing is not necessarily a function of size of sample, but rather it depends on the individual sample being representative of the whole. Since concentrations do vary in different zones in a flue, it is just as essential that spot samples be taken at several points when drawing large samples as when drawing smaller ones. It is also just as essential to observe the common precautions, chief of which is to maintain a gas velocity entering the sampling tube or pipe, equivalent to the flue velocity at the sampling point. Furthermore, when large samples are drawn it is necessary to resort to pitot tubes or orifices for measuring the volumes drawn, and this introduces another source of potential error.

When using a bag for filtering the sample, there is also the possible leakage through it unless it is hung in the open where it can be observed. It has been our experience that bags show lower contents than do the thimble samples. This is of especial importance, since any appreciable leakage in the outlet sample would result in an efficiency considerably in excess of the true value.

Probably the best indication of the accuracy of the thimble samples is the fact that close checks have been obtained between the amounts collected in a precipitator and that calculated from gas volumes and dust contents as determined by such samples. Also, the Brady method is sensitive enough to show up variations in the content of the clean gas with variations in operating conditions known to affect efficiencies.

A. F. NESBIT: As stated, Fig. 1 does not show any reference to recovery of cement dust as a part of this total area. If recovery of cement dust were to be represented as a part of this figure, what would be its percentage of the total area?

C. W. HEDBERG: Approximately 23 per cent.

A. F. NESBIT: Where are the electrical precipitator installations in operation on blast-furnace gas, and on fly ash?

C. W. HEDBERG: There are Cottrell plants for cleaning of blast-furnace gas at the plants of the Tennessee Coal, Iron & Railroad Company, Ensley and Fairfield, Ala., and the Colorado Fuel and Iron Company, Pueblo, Colo.

Cottrell plants for recovery of fly ash are installed at the following plants:

Detroit Edison Company, Trenton Channel.

Cleveland Electric Illuminating Company, Avon and Ashtabula, Ohio.

State Line Generating Company, Hammond, Ind.

New York Edison Company, Michigan City, and East River, N. Y.

Long Island Lighting Company.

Virginia Public Service.

Harvard Medical School.

New York Steam Corporation.

Duquesne Light Company, Colfax Station.

A. F. NESBIT: What are the dust contents per cubic foot of such gases?

C. W. HEDBERG: The dust contents of waste gases from powdered coal usually range from 1.8 to 3.5 grains per cubic foot at 32 degrees F., and 29.92 inches of mercury.

A. F. NESBIT: How are these weighted rods, working as discharge electrodes, from the standpoint of freedom of pendular motion tending to destroy their alinement with the pipe?

C. W. HEDBERG: All of the rods are attached to a common spacer frame in the bottom header. This prevents pendular motion in individual electrodes and the mass is sufficient to prevent all from swinging as a pendulum under ordinary operating conditions.

A. F. NESBIT: How can pipes of such small diameter be successfully used as grounded electrodes, and yet obtain good detarring at the low voltages used?

C. W. HEDBERG: The answer is that they have been used very extensively and with complete success. There are more installations in which the six-inch pipes are used than any other size. At the present time, however, eight-inch pipes are being adopted in order to obtain larger capacity in the same diameter of shell.

A. F. NESBIT: What discharge gaps are successfully used in six-inch and eight-inch pipes for this work?

C. W. HEDBERG: I do not understand exactly what is meant by "discharge gaps" unless Mr. Nesbit refers to the distance between the discharge electrode and the collecting electrode. In the case of both eight-inch and six-inch pipes, ¼-inch twisted square rods are used for the discharge electrodes. The gap, therefore, is equivalent to the radius of the particular pipe minus approximately ¼ inch to allow for permissible variation in centering of the discharge electrode.

A. F. NESBIT: For a precipitator installation of 270,000 cubic feet per minute for fly-ash recovery, what approximate length, width, and height would be required, exclusive of inlet and outlet ducts?

C. W. HEDBERG: Such a precipitator is built in three units, each unit consisting of 15 standard ducts. Its general dimensions are 20 feet in length, 40 feet in width, and 33 feet in overall height. The height above the hopper line is approximately 25 feet.

A. F. NESBIT: What gas velocities through the precipitators are found best for such cleaning?

C. W. HEDBERG: Fly-ash precipitators are usually designed for a guaranteed removal of 90 per cent. of the suspended material in the incoming gas. For this guarantee the basic gas velocity used is 8.6 feet per second.

A. F. NESBIT: You say that the discharge electrodes are self-cleaning. How is this accomplished?

C. W. HEDBERG: The amount of material deposited on discharge electrodes varies considerably for different types of precipitators and also for different gas conditions and physical and chemical characteristics of the suspended material. Ordinarily the last two are the determining factors. In the case of fly ash we have found that there is little, if any, tendency for deposits to form on the discharge electrodes and, therefore, it has been unnecessary to include auxiliary equipment for cleaning them.

A. F. Nesbit: Are there any figures to show whether small checkers would be limited to use with gases having a low dust content per cubic foot?

C. W. Hedberg: This question can best be answered by blast-furnace operators who are more familiar with the use of small checkers. From general specifications which have been furnished in inquiries for equipment where small checkers are in use, it would appear that operators consider a gas cleanliness ranging from 0.005 to 0.015 grain per cubic foot of gas at standard conditions to be necessary for this purpose.

A. F. Nesbit: Will American blast-furnace operation countenance the extensive systems of cleaning gas, such as suggested by the preliminary cleaner plus the electrical cleaner, as supplementary to the present rough dust-collector at the bottom of the downcomer?

C. W. Hedberg: As yet no cleaning plants incorporating this method of treatment have been installed in this country and we can not predict what might be done in the future. Its adoption, as has been stated, will depend on local conditions and economics. Apparently it has a place in European practice, there being built or building, one in Germany, two in Spain and one in Russia. The consensus of opinion of the Cottrell interests in Europe seems to be that it is the logical method to follow in building Cottrell plants for cleaning blast-furnace gas.

A. F. Nesbit: Is not the answer for the final solution to be found in complete cleaning in one stage, either by water alone, with its attendant cooling of the gas, or by dry cleaning alone, either by electrical or mechanical methods that will operate under all the fluctuating conditions but be continuous in operation?

C. W. Hedberg: Undoubtedly the final solution would be equipment capable of cleaning, in one stage, to whatever cleanliness is required and under all conditions of furnace operation. The writer knows of no equipment now available to the blast-furnace industry which is capable of performing in this manner without including a considerable amount of spare capacity. While it is a comparatively simple matter to build equipment which will handle a portion of the

gas from a furnace and remove practically all of the dust in a single stage, it becomes a far more difficult matter to have it perform in a similar manner when extended to handle the entire gas volume, due to the fact that smaller units frequently do not receive the full effect of such variations as occur in blast-furnace gas and dust content. For example, there are several Cottrell installations in Europe which are designed to deliver a gas equivalent to ordinary secondary cleaned gas in one stage and which do so most of the time. However, there are periods when interruption may occur in a single unit, due, for example, to a full hopper. Similar minor causes may result in interruptions in other types of equipment. Where conditions require the highest cleanliness at all times and under all conditions, it is my judgment that the only conservative procedure is two-stage cleaning, irrespective of whether it be by electrical or mechanical means or by wet scrubbing.

A. F. Nesbit: Will American practice countenance the admission of hydrocarbon vapors through bituminous coal admitted with the furnace charge, in order to overcome the back ionization mentioned, so as to improve electrical cleaning of blast-furnace gas?

C. W. Hedberg: Local conditions such as high top temperatures, which make it desirable to conserve sensible heat and water shortage which eliminates from consideration a wet scrubber system, may combine to make it desirable to add bituminous coal to the charge in order to permit the use of hot dry cleaning.

A. F. Nesbit: Are there any installations, other than experimental ones, using this expedient?

C. W. Hedberg: This method is used in the cleaning plants of the Tennessee Coal, Iron & Railroad Company, at Ensley and Fairfield, Ala.

A. F. Nesbit: Reference is made to the use of corrugated steel sheets as collecting electrodes. Have these types of grounded electrodes proved satisfactory; and, if so, on what problems?

C. W. Hedberg: Corrugated steel sheets are frequently used for collecting electrodes, principally in installations for the removal

of dust from roaster gases in sulphuric acid plants. There are a number of installations of this kind in operation, among which we may mention the Donora Zinc Works, American Zinc, Lead & Smelting Company, Ducktown Chemical & Iron, and the Davison Chemical Company.

A. F. Nesbit: Are corrugated plates preferred to pipes and flat plates as grounded electrodes; and, if so, why?

C. W. Hedberg: In the particular applications in which they are used they are preferred to pipes, primarily because of simplifications which are possible in the construction of the equipment. They have a very distinct advantage over flat plates in that they do not warp. This is important in roaster precipitators, particularly since the gas temperatures normally range from 800 to as high as 1300 degrees F. By corrugating, the plates can be built of 12-gage sheets, whereas flat plates would have to be heavier and more substantially reinforced. Provided temperatures are such that alloy must be used to resist scaling, it is apparent that corrugation reduces material costs. As compared with the heavier flat plates, there is a further advantage in cost because there is less weight to be supported.

A. F. Nesbit: Why not use "kenetron" tubes as current rectifiers?

C. W. Hedberg: The use of "kenetrons" has been considered for a number of years. The chief reason why they have not been adopted is that tests have shown no particular improvement in precipitation over that secured by current rectified by mechanical rectifiers. There has also been some question as to the life to be expected from "kenetrons" in regular operation, and while it is undoubtedly true that an extensive use of "kenetrons" in regular operation would provide information that would lead to improvements in their manufacture which would greatly increase their life, it has not appeared expedient to adopt them. It is my understanding, however, that new developments are under way which may entirely alter matters. It is impossible to say at present, however, how soon they will come into general use.

A. F. NESBIT: In the use of the chain scrapers, is it necessary to shut off the power during cleaning of the plate electrodes?

C. W. HEDBERG: It is unnecessary to cut off the power on a precipitator while the plate electrodes are being scraped.

A. F. NESBIT: What type of precipitator is used in the zinc works at Donora? What is its total capacity?

C. W. HEDBERG: The type of precipitator to which Mr. Nesbit probably refers is an exposed-pipe type using two passes with a common bottom header or hopper and separate top headers. In the first pass the gas passes downward through a group of pipes, then into the hopper, and then upward through a second group comprising the second pass. There are two distinct applications at this plant in which this type of precipitator is used, one of which has installed capacity for 30,000 cubic feet and the other 40,000 cubic feet per minute.

Mr. Blair asked about troubles in connection with the scrapers used for cleaning the collecting electrodes on fly-ash precipitators. One of our principal difficulties has been in the dividing wall between units where two units are built in one precipitator. Although there is a two-inch space between the steel wall and the nearest plate, this dividing wall warped on a few installations sufficiently to prevent the passing of a scraper chain at that point and that has resulted in breakage. In these cases, the remedy applied consisted in removing the chain. This has not made any noticeable difference in the operating results.

The limiting temperature for precipitation of fly ash with concrete plates is determined largely by the life of the concrete plates themselves. Ordinarily when a Portland cement and sand mix is used the temperatures are limited to approximately 600 degrees F. Other mixes are available which will allow higher temperatures. However, we have had concrete plates in operation in gas at temperatures as high as 800 degrees F. without any apparent effect on the plate itself. The principal objection to high temperature in fly ash collection is that it makes that much more gas to handle. Under any conditions the volumes are high, and the volume increase due to high temperatures requires just that much more equipment and space, and increases operating costs.

ECONOMICS OF THE NATURAL GAS INDUSTRY*

By J. D. Sisler†

Coal and natural gas are the two major natural fuels which are produced in the Appalachian region. For years these fuels have had their own market and their own particular uses, but the time is soon coming when these fuels will enter upon an era of competition; not particularly in the states where they are produced, but in distant cities to which they are transported. Since 1928, the range of natural-gas transmission has been extended from 250 miles to 450 miles, and lines which are now under construction will transport gas more than 900 miles. Modern pipe-line methods with enormous financial backing have brought this condition about. Within two years, three long-distance transmission lines for natural gas will reach the Atlantic seaboard. The northernmost of these lines extends from Pittsburgh to Olean, N. Y., and will eventually reach New York City. This line is a combination of old lines, some of which were used for the transportation of oil. The middle line extends from Ohio and West Virginia along the southern border of Pennsylvania to Philadelphia. This line was formerly used for the transportation of oil. The southern line which is proposed to cross the southern part of West Virginia is an eastern extension of the line from Louisville to Beaver Creek in Kentucky. This line will serve various towns in Virginia and southern West Virginia and will have its terminus in Washington, D. C.

These lines will transport natural gas from the Appalachian region and will compete with the Appalachian coals as domestic and industrial fuels. Although these fuels will be in competition, some of the loss to the coal industry will be lessened because more coal will be used for manufacturing gas to be mixed with natural gas at the distributing centers.

With the long-distance transmission of natural gas and the waning of natural-gas resources in the eastern United States have come many changes in the economics of the industry.

The natural-gas industry is classed as a public utility because many states, through a regulatory board or commission, set the sale price of natural gas to consumers. The natural-gas industry is in a

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way fortunate to have this regulation. The sale price is more or less constant, and the operators know that costs of production, sales, and distribution must be within certain limits to make a profit. Such is not the case with the coal industry. Coal producers do not know from one day to the next how much their coal will sell for and a severe cutthroat competition within the coal industry has wrecked as much havoc as over-production.

The natural-gas industry is growing rapidly. The United States Bureau of Mines has estimated that more than 40,000 miles of trunk pipe-lines transport gas to serve more than 3500 cities and towns in the United States. The pipe-line mileage is increasing by thousands of miles each year. Approximately 80 per cent. of the gas consumed in the United States is natural gas. In 1929, the consumption of gas was 2,330,000,000 cubic feet, of which quantity natural gas constituted 1,900,000,000 cubic feet.

A few years ago, natural gas was supposed to be about depleted. Discovery of natural gas in prodigious quantities in Louisiana, Oklahoma, Texas, and New Mexico, combined with more modern operating methods in the old fields of the eastern United States, has resulted in the development of one of the most profitable and basic industries in the United States. The success of such an industry depends largely upon the quantity of available gas. It is impossible to estimate the quantity of gas which is available. It amounts to hundreds of trillions of cubic feet, and is believed to be enough to serve all the districts which are now being served, as well as the districts that will be served by proposed lines, for approximately fifty years. In the old fields of the Appalachian district the writer estimates that there are between 15,000,000,000,000 and 20,000,000,000,000 cubic feet yet to be recovered. There appear to be ample reserves of the natural fuel to survive the charge-off years on all of the long-distance transmission lines which are now in existence and which are now proposed. With the sudden growth of this gigantic industry, many problems in economics have presented themselves.

The sources of large supplies of natural gas are very remote from large consuming centers. Transportation of natural gas from these points has been proved mathematically to be feasible. Time will determine whether or not these calculations have been correct. The welded pipe-line, improvements in construction methods by the

use of machinery and well trained crews, and multiple compressor stations are the largest factors in this phase of transportation.

The producers of natural gas were, in the beginning, quite pessimistic as to the life of the large fields which had been discovered in the southern and Mid-continent fields because they had the experience of the Appalachian operators in front of them, where wells were usually small and large wells declined rapidly. The prolific fields in Louisiana, Oklahoma, Texas, and New Mexico have now proved to be of substantial life, and potential production is even larger than it was first believed to be. The fears of the operators have been dispelled on this point.

Long transmission lines do not provide flexibility in supplying the consuming centers. The problem of storage at points of immediate consumption is a large one. In the Appalachian district this can be partly solved by underground storage in depleted reservoirs. In the cities of the Middle West, underground storage is impossible, and large investments must be made for surface storage to care for peak-loads, line breaks and sudden leakage. Surface storage is expensive, and much experimentation is needed to determine the extent of the storage which will be necessary.

The question of rate structures has already caused much deliberation. The rate structure which is now proposed is based on the therm, which is a unit of 100,000 B.t.u. Under this plan, gas will be sold on its intrinsic heating value instead of on its volume as has been customary heretofore. In making rate structures there is no precedent to go by and the natural-gas industry in large consuming centers must go through a period of adjustment between distributing companies and the consumers.

In some states, transmission companies are not classed as public utilities. Legislation has now been introduced in one state to make long-transmission gas lines common carriers. Gas men, of course, object to this and contend that transmission lines can not be compared with oil transmission lines. The fight between the legislatures of some states and the transporting companies will probably be quite prolonged.

This meeting is more immediately concerned with the gas industry in the Appalachian region, where economic conditions differ somewhat from those in other parts of the United States. The

natural-gas industry of the Appalachian region may be affected by the transportation of natural gas from the Mid-continent field. Only a few hundred miles of pipe-line must be laid to deliver Texas gas to Pittsburgh. It is not hazardous to guess that it will not be many years before Mid-continent gas is on the market in the seaboard consuming centers in competition with Appalachian gas.

Prepared gases in liquid or compressed form, shipped in containers for domestic use have become quite popular and they may take considerable markets away from Appalachian gas producers. Cracked natural gas may now be delivered to the consumer with a lower therm rating. It is impossible to prophesy just what the effect will be on Appalachian gas if this principle is applied to as great an extent to natural gas as cracking has been applied to the recovery of gasoline from crude oil. If it is a success, and proper rate structures are obtained, the reserve by volume of natural gas may be doubled.

There are four main factors in the economics of the natural-gas industry in the Appalachian region. These are distribution, sales, standardization of production, and conservation of gas. All of these four factors are intermingled as the result of careful planning by operating companies in order to market gas at a profit.

There are now five major producing companies in the Appalachian district. These companies have been in existence for many years. They have grown through acquisition of territory, by merger, and by consolidation. One of these companies, the Carnegie Natural Gas Company is a captive company which has been producing gas only to supply the United States Steel Corporation and allied companies. The principles of economics concerning that company are different from those of all other companies producing gas in this district.

Fifteen years ago there was a distinct feeling of competition among gas companies. A cloak of secrecy was thrown about wells when they were drilled. Offset wells were numerous. Trading leases and wells were practically unheard of. This condition no longer exists. Officials of these companies meet regularly to trade information and to talk of problems which are common to all of them. These officials give papers before scientific societies and tell of their experiences and experiments. It is through this spirit of co-operation and

friendliness that the four phases of the economics of the natural-gas industry have been developed.

Standardization of production has been brought about by blocking up leases, trading leases, trading wells, and the elimination of small-lot drilling. It has been common practice throughout the years for a group of men to lease a small block of acreage and raise enough funds to drill one or two wells. If one or both of these wells are dry the venture is a failure and the leases are abandoned before they are adequately tested and everybody loses money. This type of company has gradually fallen by the wayside. People have become wary of investments in small gas companies.

The major companies of the Appalachian district have been making serious attempts to block up large areas of leases. The primary purpose is to hold them as reserve, but two other purposes are equally important. They are, first, to minimize the number and length of gathering lines, and second, to handle leases large enough to enable an operating company to develop its properties in the proper manner, unhampered by the fear of other companies draining the lands through offset wells. Leases are being traded with or without bonuses. Wells are being traded and sold by companies in order to reduce costs of production.

The McKeesport gas pool taught the natural-gas industry a very effective lesson. It probably has resulted in the saving of as much money in Pennsylvania as was lost through it. Since 1919 there have been only two small town-lot developments in Pennsylvania. The percentage of offset wells has also decreased greatly. The publicity which was given the McKeesport gas pool not only educated operators but it educated investors. A natural-gas reservoir is much like any other container filled with a fluid or gaseous substance; the more holes which are punched in the container the more rapidly the substance will be withdrawn. It is highly unprofitable to every one concerned to produce natural gas more rapidly than should be done, and it is foolhardy to hasten production by drilling many times the number of wells which are required to drain the territory just in order to get ahead of the other fellow. The producing companies have become cautious and have realized the folly of cutthroat competition in production.

Hand in hand with the standardization of production goes the standardization of distribution. The new wells in the Appalachian district are not large. Their rock pressures have been greatly reduced since the beginning of the industry. Natural gas is now being "gleaned" in the Appalachian district. Production costs are higher, and if any saving is to be made it must be done in distribution. The standardization of production has led to savings in distribution by elimination of miles of gathering lines, and there is yet much to be done in the reduction of distribution costs.

Several companies are having much success with underground storage of natural gas, and one company is storing manufactured gas in the Pittsburgh district. If the proper place for underground storage is chosen it is certain to be successful. Underground storage eliminates the costs of building surface storage tanks in thickly populated territory, while providing an immediate reserve of gas for use in times of peak-loads and during winter months.

During the summer months a very large part of potential production is shut in. This is particularly true of companies which sell gas only for domestic use. Underground storage reservoirs enable gas companies to concentrate their gas in one area during slack seasons and draw from it during periods of large demand. Underground storage is not only desirable for local purposes, but it could be used with much success on a large scale by companies which are transporting their gas from long distances. It is a safeguard against pipe-line breaks and fluctuations in demand. Underground storage is a haven for gas being produced in areas from regions of excessive drilling.

There is a possibility that underground reservoirs can be used for mixing manufactured gas with natural gas, and for storage at the same time. It is the author's belief that in a loosely cemented sandstone which has produced natural gas, if natural gas is put back into the sand with the desired quantity of manufactured gas and allowed to stay in the sand for varying periods of time, the product will be very thoroughly mixed. It may be possible to inject specified quantities of natural gas and manufactured gas in the underground reservoir at one end and draw it out at the other in a thoroughly mixed condition and deliver it to the consumer when peak-loads demand it.

Several companies are furnishing the city of Pittsburgh with natural gas for domestic and industrial use. Each of these companies

must have its organization for production, distribution, and sales. It has occurred to the author that distribution costs, by the regulation of supply through a common gate into the city of Pittsburgh, may be further reduced. A common gate would be no more than the principle which was applied to the Seep agency for the distribution of oil in the early days of the industry.

Standardization of markets has been the subject of much experimentation by companies selling gas in the Appalachian region. When production is sold for domestic use there are approximately four months during the year when sales are much below the other eight months. The overhead of the companies goes on just the same in these slack months as it does in the more prosperous ones. Although domestic gas usually sells at a higher price than industrial gas, the profit is less. It is quite desirable to have industrial consumers to equalize the load between the summer and winter months. The ideal situation seems to be to combine industrial and domestic sales to the proper point to keep the load as constant as possible throughout the 12 months of the year.

With the establishment of long-distance transmission lines, the natural-gas industry is not only establishing a profitable business in distant cities but is stabilizing the local market. Natural gas will certainly be used for mixing with manufactured gas in the larger cities of the East. Excess natural gas can be shipped for this purpose.

The introduction of mechanical cooling and refrigeration systems has already increased the sale of domestic gas. This increase in sales is largely due to advertising by the various retail gas dealers. The use of natural gas for heating houses and buildings is also gaining, particularly in regions where the price of raw coal is high. The sale of gas for summer cooling of residences, buildings, and theaters is another means by which gas companies can increase their sales when the domestic market is slack.

The conservation of natural gas is one of the basic economic factors of the natural-gas industry in the Appalachian district. For many years, millions of cubic feet of gas were wasted because there was no market for the product. From 1860 to 1885 natural gas which was found during the search for oil was considered a nuisance and very few attempts were made to utilize it. Its occurrence was far from consuming centers. The first great forward step in the

natural-gas industry was in 1883, when natural gas was piped to Pittsburgh for use in industries. In the same year the town of Washington, Pa., was supplied with gas from wells in the immediate neighborhood. For twenty-five years many of the steel-mills, iron foundries and glass factories relied solely upon natural gas for fuel. Supplies began to fail because adequate means were not taken to conserve and equalize production.

The proper spacing of wells is an important factor in the conservation of gas. When gas is found in areas of small separate leases there is a mad rush to obtain adjoining or nearby leases and dozens of wells are drilled where a few would have sufficed. The gas is drained rapidly from the reservoirs and in a few months they are dry. Proper spacing of wells can be had only where the size of leases is adequate. Small, irregularly shaped leases invariably result in the drilling of numerous offset wells from which little profit is derived.

Throughout the Appalachian district there are dozens of small companies operating on a shoe-string. These companies may hold some very desirable leases, but usually they are small. When a well is drilled and production is found, a larger company usually comes in to offset. If the small company has a large enough acreage to protect its well it has to depend on larger companies for purchase of gas.

The elimination of shoe-string operators by consolidation or purchase conserves the supply of natural gas and removes factors which are very definitely against stabilization of the natural-gas industry. Consolidations and mergers have been frequent in the last two years and desirable results will in all probability come from them. More money will be available for the care and upkeep of wells.

The average production from wells in Pennsylvania, for instance, is less than 20,000 cubic feet a day; in West Virginia it is 40,000 cubic feet a day. Each year this average daily production will decrease. This decrease has brought about two distinct changes in the industry:

1. More attention is being given to both new and old wells. They are being systematically cleaned, and the casing and tubing are being replaced and repaired. In former years, wells which produced less than 50,000 cubic feet a day were abandoned. Wells producing 5000 feet are now capped and saved for future production.

2. Deep drilling will increase from year to year as the supply of natural gas decreases and the market price increases. Conservation methods will be applied to production from these deep sands.

The natural-gas industry of the Appalachian district is organized upon a very solid and definite economic plan. Operators have benefited from the experience of operators in the newer fields of the Middle West and the western coast. The proximity to a ready market enables Appalachian operators to produce gas from small wells and sell it at a higher price than the gas from distant points; but this advantage is not entirely because of geographic location. It is because producing companies have realized that co-operation and sound business tactics are the secrets of financial success in producing a natural product.

DISCUSSION

R. H. Johnson:* I was interested in the reference to the cracking of natural gas. Would you go a little further into that?

J. D. Sisler: I do not know a lot about it. It is very largely in an experimental stage. Possibly Mr. Meals could tell you; he knows more about it than I do. There seem to be certain interesting possibilities in the practice.

S. W. Meals:† The cracking of natural gas was carried on in Los Angeles several years ago. There was a shortage of gas, and in order to meet that situation they turned natural gas into their retorts and in that way cracked their gas to supply their consumers without any interference at the burner. The burners were all adjusted to manufactured gas and had they turned in natural gas, of which they had plenty, they would have had trouble right away. The only way out of the situation was to break up the hydrocarbons and by doing that they were able to supply the consumers without making adjustments at the burners.

R. H. Johnson: What is the reaction?

S. W. Meals: I assume they break it up into its component parts, for I know that after cracking they have more cubic feet of gas than the natural gas put into the process, but of less B.t.u. value.

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†President, Carnegie Natural Gas Co., Pittsburgh.

R. H. Johnson: It seems to me there is a lot of thermal value lost in that operation.

D. P. Hartson:* There are at least two different processes and cracking of various degrees between the two. A few years ago the Louisville Gas and Electric Company tried cracking natural gas by running it through a water-gas set. In this process, for each thousand cubic feet of natural gas they used 15 pounds of coke. They got out of the process approximately 2250 cubic feet of gas (which was 90 per cent. hydrogen) and about seven pounds of carbon black. There is a loss of thermal efficiency in this process, but it has some advantages where you are mixing a gas of higher gravity with your natural gas. By putting the hydrogen back into the mixture you offset the increase of gravity which is brought about by the inclusion of the gas of higher gravity. In some cases butane is used to enrich a mixture of gases. As you know, this has a gravity of 1.95, and if it be used in any quantity it materially increases the gravity of your mixture. The same thing is true if you are using producer gas to increase the volume of mixed gas. In cases like this it is of considerable advantage to offset the higher gravities by the use of hydrogen. You will also note that you have more than doubled the volume of gas by the process, for, as I said before, each thousand cubic feet of natural gas produces about 2250 cubic feet of hydrogen. The process is not a complete success, but I understand it is being used to advantage in some places.

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STORAGE OF GAS IN OIL AND GAS HORIZONS BELOW WORKABLE COAL-BEDS*

By S. W. Meals†

Storing gas in oil and gas sands which underlie workable coal-beds is practical and need not be considered as a hazardous undertaking when all facts are carefully considered and fully analyzed. The following are some of the problems to be undertaken:

1. A careful survey of the area of the field, with location of all wells.
2. A log of each well, and the size or volume when drilled in, if possible.
3. The original rock pressure and the present pressure on the sand.
4. Whether there is an encroachment of water in the gas-producing sand in which the gas is to be stored.
5. How the wells are cased or tubed, and the depth of the formation below the coal.
6. The formations between the sand and coal and whether gas, oil or water was found in any of the formations in this area.
7. The rock pressures of gas found above the sand intended to be used for storage.

As I stated, it is not necessary to store gas at high pressures; in fact, we would not consider it economical to attempt it. In selecting a storage field one should look for an oil sand or gas sand which is depleted, and perhaps free from water. In southern Pennsylvania and West Virginia there are a number of gas-producing formations from the Big Injun down to the Bradford sand that may be ideal for storage purposes. In this same territory are a number of formations which usually carry water, such as the Salt sand or Murrysville sand. The water-level in these formations is usually high; in fact, in many wells we have known the Salt sand water to rise to the top of the hole.

The United States Bureau of Mines recommends the mud-laden fluid for shutting off gas. Operators use it in sealing off large gas wells with high rock pressures. Throughout the West, mud is the

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antidote for too much gas. As the weight of water and mud with a depth of 100 feet is more than 43 pounds to the square inch, you can readily see that it would require a very high pressure to force its way through 1000 feet of water and mud.

In the McKeesport field, where many wells were drilled, some abandoned wells may not have been plugged as the present West Virginia law requires. The Speechley sand, found at a depth of about 3000 feet, is not affected by water from formations higher up, although the Murrysville sand in that field carried water. As proof of this fact the gas from the Speechley sand was under vacuum for several years, yet there was no encroachment of water on this sand. Nature must have done its work or this sand would have been flooded.

When the Speechley sand was under 18 points vacuum, the Sixth sand (about 600 feet above) showed a rock pressure of 200 pounds, and the Hundred-foot sand (found still higher up) about 70 pounds. A couple of wells which produced gas from the Big Injun sand had rock pressures of 160 pounds. If these sands had not been sealed by cavings, or properly plugged, no such rock pressures in the upper formations could be found, as the pressure would have forced its way to the deeper sands then under vacuum. If the upper formations carry rock pressures of 200 pounds, should the Speechley formation be utilized for storage and sufficient gas be stored to raise the pressure on the Speechley sand to 50 pounds, this pressure could not force its way up through 200 feet of cavings, and surely not against the 200-pound pressure found in the Sixth sand.

We know that the coal operators view with some alarm the drilling of wells for gas or oil through the coal seams; yet, in some respects, I think the gas operations have been a blessing to the coal operator. If the gas found in the coal measures, or in formations above or just below the coal, had not been disturbed, in my judgment mining coal would present greater hazards than are brought about by reason of wells drilled through the coal seams.

I spoke of the West Virginia law regarding plugging. You recall that H. Foster Bain, Secretary of the American Institute of Mining and Metallurgical Engineers, appointed a committee to draft a model law for the use of the legislature of any state concerned. The committee made its report and a copy reached Robert Lambing, chief of the West Virginia Department of Mines. Shortly after-

wards, the West Virginia Legislature convened and House Bill 305 was passed and became a law June 1, 1929. The regulations seem to be working very satisfactorily to both the coal and gas operators. I believe this Society should become active and see that such a drilling and plugging law is placed on our statute books.

In the United States a vast change in the use of fuel is taking place, with tremendous quantities of gas supplanting coal.

Gas produced last year was equivalent to more than one-sixth of the coal production. The United States Bureau of Mines reports that for 1929 a total of 1,917,693,000,000 cubic feet of natural gas was produced and marketed, a gain of 22 per cent. over 1928. Less than 20 per cent. of this natural gas was utilized by domestic consumers, and about 80 per cent. in industrial plants and in oil-field and gas-field operations.

The sale of manufactured gas amounted to 524,100,000,000 cubic feet, an increase of six per cent. over the preceding year. Of this amount, over 163,000,000,000 cubic feet were industrial and commercial sales, an increase of 10 per cent. over the preceding year. The production of coke-oven gas for 1929 amounted to a little over 800,000,000,000 cubic feet; crude oil production was 1,000,000,000 barrels (an increase of about 11 per cent. over 1928); production of bituminous coal amounted to 532,000,000 tons and anthracite to 77,000,000 tons.

In the natural-gas industry there were 5,116,000 consumers as of December 31, 1929, compared with 4,344,000 in 1928, with an average consumption per domestic consumer of over 73,000 cubic feet. In the manufactured-gas industry, the total consumers in 1929 reached 12,139,000, with an average consumption per customer of 43,000 cubic feet a year. In this latter industry, only 23,100,000,000 cubic feet went into house heating, while, in the natural-gas industry, a much larger percentage of domestic gas consumed was for house heating. With a total of less than 18,000,000 customers in the gas industry, the house-heating load in the country has hardly been begun.

It is stated that over 61,000 distinct manufacturing processes require the use of gas. We are entering the age of "superpower." Who can safely say that dreams of to-day may not revolutionize the coal, oil, and gas industries within another generation? From present observations, the trend is toward a gas system, connecting the West

with the East, the North with the South. There are over 57,000 miles of gas lines in our country to-day, with a number of long-transmission lines under construction and more contemplated when details can be worked out. Once a consumer of a gas fuel, it is difficult to return to the use of solid fuels.

The use of gas means domestic convenience, industrial efficiency, and smokeless cities. The smoke evil in our cities, due to burning coal, is costing civilization more than the profit realized by the coal industry to-day. It has been estimated that smoke causes an annual loss to the United States of over $500,000,000. Why, then, should not solid fuels give way to gas? Burning coal in its raw state wastes by-products of greater value than the first cost of the coal. Under these conditions, is it not time that the coal operators view this rapid expansion of the gas industry rightly and go along with the trend through the installation of gas plants and cracking plants at the coal-mines and the conversion of coal into gaseous fuel and anti-knock gasoline? The natural-gas industry is leading to-day, but sooner or later coal products will be needed to meet the growing demand for gas fuel.

If the heating load in this country is to be supplied with a gas fuel, should not the coal industry furnish this product to the gas industry for distribution through the network of pipe-lines now laid and to be constructed? Only through the co-operation of the two industries can the public get this magic fuel so much in demand, at prices which it is able and willing to pay. The modern cracking process and the production of still gas from the distillation of petroleum are becoming factors in the gas supply. Now comes the hydrogenation process, which may have a far-reaching effect not only upon the petroleum industry, but upon the gas and coal industries as well. It is claimed that through hydrogenation it is practicable to convert coal into liquefied hydrocarbons. By this method, liquefied coal, shale oil, coal-tars, and crude petroleum and its residues may be converted into high-grade finished products.

Scientific research is making such progress these days that no one can guess what the future may bring forth. In a paper read at the American Gas Association convention at Atlantic City last month, on the subject of long-distance transportation of natural gas, Edgar G. Hill expressed the thought that perhaps some chemist will find a

"catalyzer" which will liquefy gas at a nominal cost and regasify it at the market, thus saving one-half the cost of transportation, since a 12-inch line, using 25 horse-power per mile, will transport as much heat in the form of liquid hydrocarbons as a 24-inch line at 600 pounds pressure, using 125 horse-power per mile.

The erection and operation of gas plants and cracking plants at coal-mines would be a forward move in true conservation. For the coal industry to carry on along the lines at which I have hinted, large storage reservoirs will be required to operate and regulate the delivery to meet the fluctuating demand in house-heating requirements.

In the Appalachian fields and in many of the western sections of this country, gas- and oil-fields are either underlying, or contiguous to, the coal measures, and in many sections depleted oil sands or gas sands are available for the storage of either natural gas or coal gas. Oil sands or gas sands which have been depleted are of no value to the land owner, but may be of much value to the public through their use as storage reservoirs in conserving gas and as a convenience for marketing.

Coal gas can be stored as readily as natural gas if it is properly cleaned and purified. In ordinary operation it is not necessary to go to high pressures in storing gas underground. In a number of storage fields now in operation, with 50 pounds differential over line pressure, 10,000,000 cubic feet a day can be withdrawn. The renowned storage field in Kentucky has had close to 8,000,000,000 cubic feet of gas stored with less than 80 pounds rock pressure. In Texas, one company had millions of cubic feet of gas injected into storage without raising the rock pressure over 35 pounds. In this case the gas stored was a lean gas, and due to hydrocarbons in the sand it was enriched. The recovery was about 30 per cent. more than the gas metered into the sand. No doubt this increase was due to the opening up of sealed pockets in the pores of the sand.

Recently the Canadian Gas Company began storing surplus natural gas, from oil-wells in the Turner Valley field, in depleted sands in the Bow Island field located about sixty miles west of Lethbridge. The company has installed 1200-horse-power compressors, and is spending $200,000 on this project. The expense of storing natural gas is relatively slight in comparison with manufactured gas, due to the cost of the cleaning and purifying process.

Oil and gas are found in stratified rocks, the strata consisting of layers of sandstone, limestone, and shale. When a structure is properly closed, oil or gas may be found entrapped in the underlying reservoirs. The pressure found in the rock formations depends largely upon the overburden. The pressure varies from 30 to 40 pounds for each 100 feet the pool is found below the earth's surface. At 1000 feet in depth, the original rock pressure, as it is called, is around 350 to 400 pounds; at 4000 feet, the rock pressure runs up to 1600 pounds.

When a hole is drilled into the reservoir, permitting a drop in pressure, the gas expands and moves towards the point of lower pressure, driving ahead of it any reservoir content which lies in its path. Gas which has been dissolved in oil comes out of solution and leaves the oil more viscous or more difficult to move. The gas pressure or stored energy is the motive power that moves the oil to the well or to the surface. Without this motive power it is almost impossible to extract oil from the sands. If properly controlled, it can be made to increase greatly the percentage of oil recovery. It is estimated that not over 20 per cent. of the oil in these reservoirs has been removed. Repressuring the sands for the recovery of entrapped oil seems to me the logical method, as it not only conserves the gas, but recovers oil that otherwise would be lost.

A secondary influence in oil recovery is water encroachment induced by hydrostatic head. In some sands it is an expulsive factor in oil recovery. It is not practicable in all sand formations.

Throughout Western Pennsylvania and West Virginia there are many producing formations or sands. From the Pennsylvania state line, on the north, to the Kentucky border, records will show some twenty-five distinct formations underlying the Pittsburgh coal area, in which gas has been found in various localities. Opinions differ as to which of these sands has produced the largest volume of gas. In my judgment, the Big Injun sand, found at a depth close to 1300 feet below the Pittsburgh coal, if records had been kept, would record the largest volume of gas of any of the known formations throughout the territory referred to. This is a massive sandstone having a thickness of over 200 feet, and overlying this sand is found about 50 feet of limestone, known by the operator as the Big lime. It is an important marker for the driller. Between the bottom of the

Pittsburgh coal and the Big lime, the driller finds what is known as the Big red—a formation which caves—and if water is found in the Salt sand, the driller is fortunate in reaching the top of the Big lime or Big Injun sand, where a string of casing is set to shut off cavings and water. Nature seems to have provided these caves to seal off the producing formations below. In some sections, gas has been found above the Pittsburgh coal in formations that have produced as much as 500,000 cubic feet of gas a day. In Greene County, Pa., and Wetzel County, W. Va., many wells are producing gas from the Pittsburgh coal seam. Volumes of as much as 1,000,000 cubic feet have been found. The rock pressure varies from 80 to 150 pounds. Near Hundred, W. Va., there is a well which is producing from the coal and which has been in operation for at least 25 years.

The ruthless destruction of our oil and gas supply is directly due to the type of ownership fixed upon oil and gas in the United States. If the state has the constitutional authority to regulate the extraction of oil and gas and the limits of the reservoir defined, so that each owner's proportion of the oil and gas in a common pool could be fixed and determined while these products are still in the reservoir, much larger volumes of oil would be recovered and the gas would be conserved with a great reduction of waste and operating expense. It will require "unit operations," covering an entire pool, to reap the benefits of conservation, increase recovery of both oil and gas, and decrease operating expenses. The same is largely true if we utilize the depleted pools for gas storage.

DISCUSSION

D. P. Hartson:* I feel rather embarrassed in attempting to discuss this paper. Mr. Meals, as we all know, has been in the gas business for a great number of years, and he certainly knows the subject. He has had charge of the production of natural gas, and of its transportation, and its distribution to the customer. He has also had the same experience with manufactured gas. In fact, the firm with which he is connected is probably the largest user of energy in the gaseous form (manufactured and natural) of any firm in the world. When it comes to storing natural gas, Mr. Meals has had, perhaps, more experience than any one else of whom I know.

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Personally, I have had no experience in the actual storing of natural gas. In common with all others who have something to do with the matter of supply to their distribution systems, I have been very much interested in the possibilities of storage. I believe that it is something that we may come to some time in the future.

Every natural-gas company which is selling gas for domestic heating is bound to have a very poor load-factor. The heating season in this part of the country, as you know, is rather short and the capacity of your pipe-line systems which have been installed to take care of the house-heating load is used to full capacity possibly only two or three days a year, and, in many cases, 90 per cent. of the distribution and pipe-line capacity is used for not more than ten days a year. This means that we have an enormous investment made to care for a relatively short load. Most of the companies in this vicinity, like our own company, made this investment several years ago to take care of a large industrial and domestic load, and for us the matter of providing a storage field to help our transportation or distribution system is not quite as necessary as in the case of a company which is just laying out its system.

We have all been very much interested in the great expenditure of natural-gas pipe-lines in the Middle West. If near some of the cities which these pipe-lines are to supply they could obtain an underground storage for natural gas, their investments in pipe-lines would be very greatly reduced because of the fact that they could store gas during off-peak times and use it for peak-load deliveries. One of the chief concerns in installing these long lines is the matter of load-factor and, as you know, many of the pipe-line companies have tried to build up an off-peak load in the form of sales to industrial users in order to keep their lines busy during the summer and pay carrying charges which go on whether the pipe-line is used or not.

I want to back up what Mr. Meals has said about the matter of pressures. I do not believe that any of the companies which are storing gas in old fields put back into the field anywhere near as much gas as had been taken out of those fields; therefore, the pressure which they are going to build up is nowhere near the original field pressure. In fact, they are restoring to a partial degree only the conditions that formerly existed in the field. When we speak of a field as being exhausted and suitable for gas storage, it does not mean, of

course, that all of the gas in that field has been withdrawn and the pressure reduced to zero. A field which still has ten or fifteen pounds rock pressure might be considered as exhausted and very suitable for the storing of natural gas. In many of the fields which have been used or which have been considered for use for storage, the amount of gas which it would be economical to put back into the field would raise the rock pressure of the field only a very few pounds.

As I said before, the proposition of storing natural or manufactured gas in underground reservoirs may be a very great saving not only for distribution but for transportation and production facilities. In the case of manufactured gas, it is practically impossible to operate without some storage facilities. Usually these facilities are in the form of the gas-holder. To operate a manufactured-gas plant efficiently and economically, it can not be speeded up and shut down intermittently, but rather should be run at as nearly full load as possible. It is, therefore, of great advantage to be able to store gas at times of the day when it is not being used by the customers. In fact, there are, at the most, only two or three periods during the day when the full capacity of the plant might be required. If a manufactured-gas company can find a suitable underground reservoir for storing gas, it will permit the operation of the manufacturing plant on an even and economical schedule. The proposition is somewhat different with natural-gas companies which depend upon the production of many wells to supply their needs. Nevertheless, as I have said before, the use of underground storage may be of considerable saving in pipe-line capacity inasmuch as the gas can be put into storage during off-peak periods and used during the period of highest demand.

L. E. Young:* We have as a speaker this afternoon a man who is an expert in his field and who knows more about what has been done and what can be done than most of us here to-day. It seems to me that the presumption that the coal men are interested in the question of storage is justified. We are particularly interested in the storing of either natural gas or manufactured gas and I should like to suggest several questions which I hope will be answered at an appropriate time.

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1. What is the ratio between the cost of storage on the surface and storage underground? It seems to me that is a very important point.

2. Thinking only in terms of manufactured gas and primarily of the Pittsburgh district, I wonder to what extent that gas would be enriched by putting it back in the ground. I understood you to say that 20 per cent. of the oil in the sand is recovered generally. If we put gas manufactured from Pittsburgh coal back into the ground would it be enriched, and if so, how much?

3. What is the feasibility of developing the storage areas in sections where there never has been any oil- or gas-field? Suppose, for example, that there is a stratum of porous rock near some one of our big cities, Chicago for instance, or Boston, or Toronto, what would be the possibility of going into that area and putting natural gas in the ground in the summer time and recovering it in the winter time?

S. W. Meals: As to the comparison between the cost of storing gas underground and on top of the ground, the original cost, say of a 20,000,000-foot holder like the one that was erected in Chicago a year ago, is in round figures about $2,000,000. The cost of operation, I assume, would be the same whether underground or above ground, but in operating a 20,000,000-foot holder you are limited to that amount. If we attempt to store our waste gas it would take a whole flock of holders. With a reasonable underground storage, you could pump in to-day and take out to-morrow, or if you did not have use for the gas, you could continue pumping to the full storage capacity. For instance in the McKeesport field, I believe Mr. Robinson stated that after a few wells had been drilled they estimated the field would produce 20,000,000,000 cubic feet when the rock pressure was down to atmospheric pressure. From the above estimate, we figure that with a 50-pound rock pressure we ought to have about 400,000,000 feet stored. When we attempted to try out this storage, our idea was to store only waste gas over the Saturday shut-down and take it out on operating days, so we never build our storage up to 50 pounds.

Regarding the recoverable percentage of enriched gas, I can tell you that with the manufactured gas we put in the B.t.u. value was around 580, and we have taken out gas with a B.t.u. value of

about 620—an increase of say 40 B.t.u. per cubic foot. The more natural gas in the storage field the greater the recovery. For instance, I spoke about the gas stored in Texas. They had a line that ran through an old oil-field and they decided to store gas in that sand. They tell me that this was a lean gas that was injected into that sand. When they recovered it, the value of the gas was increased about 30 per cent. and the volume about 30 per cent. They could not account for that volume as the field was entirely exhausted. I have a theory that in this sand there were pockets that were sealed off, and injecting the higher pressure into the sand opened up some of these pockets and they actually measured out 30 per cent. more gas then they put in.

I am very skeptical in regard to storing gas in sedimentary rocks. You would have to have formations that were porous enough to take the gas.

J. F. ROBINSON, *Chairman:** I read an article the other day regarding an application for patents for storing gas in water-saturated sand. I do not know how it could be patented.

J. D. SISLER:† The question of the price of storing gas in oil-bearing sand, as I said, is governed by several factors, one of which is the recovery. Some of the gas injected into the sand would be trapped and thus it would not be possible to get it out again, particularly if the sand were comparatively level. I think the element of structure enters in very strongly. In a sand which is upturned and contains water, the normal tendency would be, when gas is injected, to push the water down the slope to the other side. But unless you had that structure I am afraid the gas would be trapped.

J. F. ROBINSON, *Chairman:* I think that is absolutely correct. Structure is going to play a very important part.

M. D. COOPER:‡ The storage of gas in depleted oil or gas sands is a subject that arrests the attention of the mine operator.

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Since 1919, production of coke at by-product ovens has exceeded production at beehive ovens, so that at present by-product ovens are producing nine-tenths of all of the coke manufactured in the United States. With the rapid growth of the modern oven has come the problem of the storage, distribution and use of the gas now produced in great quantities but formerly lost in the atmosphere by the older type of oven. Since the operation of the by-product oven must be as nearly continuous as possible and it can not be started and stopped as easily and with as little damage to its construction as the beehive oven, it follows that the production of gas must be continuous. With fairly steady production, some means must be provided for storage to absorb the shock of daily, weekly, or longer periodical variations in demand by the consumer.

Storage underground is a new method. It is evidently cheaper than storage in tanks and, as brought out in the paper by Mr. Meals, there appears to be no loss either in quality or quantity. However, in possible effects on mines, the question immediately arises as to whether there is any danger in the method.

Exhaust systems of ventilation in gaseous coal-mines are generally favored. They are simple. They tend to draw off gases that otherwise might be driven back into abandoned or worked-out areas. Fresh air is drawn into the mines along the main haulage roads so that locomotives and other equipment operate in air free from gases that may pollute the return air currents. The principal objections to the exhaust system are the discomfort to men who work at the bottom of the shaft, and the freezing that occurs along the shaft guides in winter.

The very advantages of the exhaust system are the factors that indicate danger in the storage of gas underground. As a mine develops, gas in the coal may be given off to such an extent that on the retreat the mine may be non-gaseous. However, if depleted wells are then used for storage of gas, is there not danger that through cracks or pore spaces gas will get into the mine?

In Ohio, the disaster that occurred this month with the loss of more than 80 lives illustrates once more how terrible a gas explosion may be when propagated by coal-dust even when the damage to the mine is relatively slight, as it appears to have been in this case. The mine operator is, therefore, apt to view with alarm a system of gas

storage that may increase the hazards of a business that already has hazards enough.

It may be that pressures employed in forcing gas into depleted areas are less than rock pressures; but account must be taken of the fact that strata are much disturbed during retreat operations in mines when pillars are removed and the roof caused to fall, sometimes over wide areas and to considerable heights. This may interfere with wells and make leakage possible.

As an afterthought, and along the same line of reasoning Dr. Young used, it occurs to me that, where the cover is heavy enough to prevent leakage, it might be possible to use abandoned coal-mines for storage purposes. That has not been brought out, but it seems to me it offers some possibilities.

G. F. Osler:* The speakers just preceding me brought out some points which I had expected to discuss.

One very important point in the paper is the proposal to manufacture artificial gas at the mines and store it. This is a very interesting prospect. We could not expect the coal industry to reap the benefit at once, but it is something to study.

In the last ten years the coal industry, particularly the bituminous coal industry, has been on a downward trend, and if the manufacture of gas from the bituminous coal at the mines can be carried on at a profit, or even so that the operator can break even without large expenditure for equipment, it is something that should be investigated and investigated very soon. We can not expect those outside of the industry to do the research work for the coal operator.

The item of transportation of the gas is one that largely enters into this matter, as the cost of producing coal now is less in most cases than the cost of transportation, even to nearby markets. Naturally the comparative cost of the fuels at the points of consumption will be the largest factor in deciding whether gas will supplant raw fuel.

We are all aware that in the Pittsburgh district the adjustment of freights, especially on coal, has been, and now is, a bone of contention between railroads and coal producers. At the present time there is a potential coal-producing capacity of over 100 per cent. more than consumption, and in view of the fact that more natural gas is

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produced or ready to be produced than there is a market for, there are plenty of problems contained in the proposition to manufacture gas at the mines and store it for winter consumption.

We know that gas requires better furnaces than coal, and it will be quite a while before coal is supplanted right in the immediate location of the mines by gas or coke or any other fuel. We know that, if coal operators open up their mines for the purpose of manufacturing coke and gas, a large expenditure of money will be necessary for equipment and a large storage space required for the coke; but it would revolutionize the whole coal industry, and I think Mr. Meals brings that out. He had vision and possibly has hit on something the coal operators have missed.

The second thing I have to touch on, on account of my experience with mines in the gas and oil fields, is the question of safety. Mr. Cooper touched on this very briefly. I have in mind one case in particular where the surface was broken by mining and the casing of an oil-well was damaged. We had a place of that kind where the oil operators came to us and said they were unable to pump oil from a well that had been in operation for twenty-five or thirty years. They pumped only once or twice a week, getting only a couple of barrels at a time. I went in the mine with the representative of the oil company and we went back in the old workings that had not been operated for twenty-five years but fairly close to the new operation where we were taking out pillars. This work had broken the surface and had pulled the overlying strata so as to crush or kink the casing in such shape that they were unable to pump through it and could not get their tools in to ream the hole. We got back within 50 or 75 feet of this well, but could not go any farther. There was a decided smell of either oil or gas in these workings.

In the McDonald mine, on the day of the explosion of the Etna Chemical Works at Oakdale, when not more than 500 or 600 feet from the opening, we cut into an abandoned oil-well and one of the men dropped his lamp and set the oil on fire. The assistant mine foreman got all the men out of that part of the mine, but one man went back for his dinner bucket, and when coming out again became confused and stepped through a door into the smoke and was killed.

Mr. Cooper spoke of the exhaust fan used in ventilating mines. I do not have much fear of the exhaust fan pulling the gas out of

an old well, because the suction created by mine exhaust fans is very low. Even at five inches of water-gage the suction is only about 26 pounds per square foot. I feel satisfied that there are mines in this district where oil-wells and gas-wells were opened up and never sealed; and in lots of cases the casing has not been pulled. If it were not for the presence of carbon dioxid gas in the old workings there would be great danger of gas from these wells finding its way into the ventilation currents and explosions might occur. I do not know how many oil men here have had experience with fires from explosions and explosions from fires in mines; but anybody that has had experience in cleaning up the mess afterwards will think a long time before he creates an additional hazard in a mine. We have enough now. The hazard of gas explosion has been reduced considerably, but explosions still occur. Explosions of gas in mines do not affect a man or two, but usually kill quite a number, by the direct force of the explosion, by flame, or by carbon monoxid gas. If artificial gas is stored in the depleted oil or gas sands under mining operations, especially under old workings, there is bound to be a hazard. In new mining operations, as the work approaches known wells drilled through the coal to sands in which gas has been stored, precautions might obviate the danger, and when wells were encountered they could be plugged. I know of mines with forty or fifty holes drilled through the coal, the casing being pulled in some cases and in other cases not pulled, and no exact record was available of the location of them. If a hazard is created by this storage I would expect it in these wells where casing had not been pulled. I may be wrong on the whole proposition, and I hope I am.

S. W. Meals: Regarding the matter of casing in the wells, I would much rather see the casing pulled out of any well even if it had never been plugged. As I mentioned in the paper, nature seems to take care of that by the cavings and the water on the formation which settles to plug off the sands so that I doubt if the pressure in any of the formations where the gas has been taken out in this section of the country would be great enough to force up through the water. But if the casing is left in it, it would keep the cavings from falling in and there might be danger of gas getting in and coming up. I believe that anybody in the gas business feels that the man that goes down in

the mine deserves every protection possible. Every precaution should be taken and any one selecting a storage, as I stated, should make a careful survey to get the information about these old wells so they can be watched. In our operations I do not know of any well that has ever shown gas leakage after it was properly plugged. I have in mind a well drilled years and years ago down in the Fairmont field, and gas was found in the salt sand. There isn't any water in that formation at that point. The well was never plugged. There was no gas from the lower formation, but the gas from the salt sand burned there for years. That was right in the heart of the Fairmont field. I don't think anybody would want to store gas in that formation. The thing to do is to go down into the Big Injun sand and not to try to store gas in the upper formation.

Some one spoke about using abandoned mines for storing gas. I do not believe it would be practicable to seal off all the openings. I believe one company tried to store gas in a deep mine where salt had been taken out. The trouble was the impossibility of sealing the mine tightly enough to hold the gas. It would, of course, be ideal storage if that could be done. There are 43,560 cubic feet in an acre one foot thick. Your coal seams are about 10 feet thick, and 500 acres would hold a lot of gas.

L. E. YOUNG: In the area in which you are storing gas, over what area laterally does the pressure build up? Have you anything to show how great an area is affected by increasing the pressure? Do you suppose the whole field pressure depends on the pressure of the intake?

S. W. MEALS: Yes, I have watched that very carefully. We have in the middle of one field a well in which we have never stored gas. That is the one I refer to for the purpose of keeping a record of what the rock pressure is on the sand in which gas is stored. The gas stored in that field has never been over 45 pounds. The original rock pressure was over 1200 pounds. As I stated, in the McKeesport field about 600 feet above the Speechley sand is the Sixth sand. The present rock pressure on this sand is about 200 pounds, and above the Sixth sand we find the Hundred-foot sand and there is about 70 pounds rock pressure on it. It would be impossible to have that pressure if there were any connection between the lower sand and the

upper sand, for several years ago they were taking gas from the Speechley sand out under 18 pounds of vacuum, so if there were any connection between the upper and the lower sands you would never get the rock pressure found in these upper formations to-day.

L. E. YOUNG: Suppose you increase the pressure over ten pounds, what would you get in this well where you can measure pressure? Do you get a corresponding pressure at once?

S. W. MEALS: If you shut off the wells after you pump back into a number of holes you get it equalized in a short time.

L. E. YOUNG: Over the entire area?

S. W. MEALS: Yes.

L. E. YOUNG: Doesn't that indicate some connection between these wells?

S. W. MEALS: Only in that particular horizon. It does not affect wells above that.

L. E. YOUNG: Is there more or less free circulation of gas under that pressure in that horizon?

S. W. MEALS: Yes, it covers the entire field.

W. E. FOHL:* My lack of experience in the actual storing of gas will compel any discussion I had in mind to be general. In addition to that, most of it has been anticipated. All coal men realize that for many years there has been a great deal of waste in the methods of mining coal. The picture Mr. Meals has drawn of gasifying coal at the mines and turning it into the network of pipe-lines spread over the country is certainly a very attractive one. I can readily see that it may not be many years until we shall be discussing this question of gas storage from an entirely different standpoint. Instead of the coal man wondering whether he will let the gas man store fuel under his operating mine, he himself may be manufacturing large quantities of gas which he will want to store, so that his question will be, "Can I simultaneously carry on safely the two operations of mining coal and storing gas beneath it?"

*Consulting Mining Engineer, Pittsburgh.

Mr. Meals mentioned the West Virginia Drilling and Plugging Act, having to do with the drilling of wells through operating coal seams and workable coal-beds. It was my privilege to be associated with that work many years, starting in 1913. I may say that these West Virginia regulations are the result of more than two years of strenuous effort on the part of a large committee appointed by the American Institute of Mining and Metallurgical Engineers, and their efforts were seconded by people called in from both industries. A large number of conferences were held and from those conferences preliminary drafts were made and distributed. People all over the country who might know about these matters were invited to send in suggestions, and many of them did so, so that the regulations as they now appear in the West Virginia statutes have had the scrutiny of people who know all over this country. The particular bearing they have on this problem is that arising from the manner in which the plugging of abandoned wells is to be done.

What Mr. Meals has said regarding precautionary measures should be emphasized.

In a previous paper* given by Mr. Meals, I find also this recommendation:

> "Before attempting to store gas in the sands, well openings into the sands should be carefully cleaned and cased to the top of the formations expected to be used as storage bins in order that no water, salt, tarry substances or cavings are forced into the sand pores to hinder the free flow of gas into the formation."

I take it that this recommendation is for the protection of the wells without reference to mining conditions and that, in addition, all wells will be properly plugged.

With all these precautions taken, I see no reason why the measure proposed by Mr. Meals concerning storage can not be put into effect, successfully and safely; especially when account is taken of the fact that it is not proposed to store gas in any sands above the Big Injun, and the further fact that in the strata overlying this sand natural caving seals wells which have been abandoned.

While, as Mr. Cooper has pointed out, ventilation of coal-mines is generally carried on by the exhaust system, it does not appear to me that any danger could arise from this in mines where wells have been securely plugged far beneath the coal-bed.

*Unpublished.

Concerning his suggestion that abandoned mines might be used as storage reservoirs, I agree with Mr. Meals that this would not be feasible, especially if mining has been properly done and the overlying strata broken.

S. W. Meals: Information Circular 6195 of the United States Bureau of Mines is entitled "Notes on Precautions To Be Taken When Drilling Oil or Gas Wells through Workable Coal Beds or through Mine Workings." I want to quote therefrom as follows:

"The added hazards to mining incident to oil and gas wells penetrating the coal measures in proximity to mine workings, have long been recognized in those fields where the extraction of oil, gas, and coal, has been in progress for a number of years. The history of these fields is replete with stories of serious mine fires, explosions, and miraculous escapes from both fires and explosions due to either oil or gas finding its way into the mine workings through the strata, or by mining into an unknown or uncharted and abandoned oil or gas well that had not been properly plugged."

There are a lot of places I can pick out where many wells are drilled in a small area. I don't think you can trace serious explosions to either oil or natural gas. I would like to ask Mr. Fohl if he has any records on this subject.

W. E. Fohl: Mr. Meals asked me that question in advance of the meeting, so I am in position to answer it. It happens that in 1927 I delivered an address before the Society* which treated of the recovery of petroleum from coal-beds, and as part of that address I made it my business to look up all the accidents which were traceable to the drilling of oil-wells or gas-wells through coal fields. I took all the records of the United States Bureau of Mines and also sent out inquiries in connection with these drilling regulations asking for accounts from all over the United States as to accidents traceable to these sources. Without troubling you with the details, I call attention to the summary which says: "We find between 1894 and the present day [January, 1927] 15 cases of explosion from oil or gas in coal-mining operations, resulting in nine accidents, seven of which were fatal." And if my memory serves me I think that among those there was no major accident, an accident involving more than three or four individuals. So I would say as to this paragraph read by Mr. Meals

*Proceedings, v. 43, p. 119.

that it is overemphasized. That does not mean that there should be any decrease in caution. We appreciate the dangers connected with drilling wells through coal-mines and I believe in formulating drilling regulations everywhere, such as the West Virginia regulations, that will take the best possible care of these dangers.

R. H. JOHNSON:* I am impressed by the question of Dr. Young as to the possibility of finding some water-bearing horizon, near the city of Chicago, say, that could be used for storage. In my opinion, the outlook is very bad. If this reservoir is filled with water and there is no oil or gas, the energy required to introduce that gas would be excessive. It is not a question of just driving it into that reservoir—the reservoir is filled with water, and around that reservoir we have rocks of much lower porosity, and our experience in trying to force gas into water-filled sand shows that the resistance is so great that, in my opinion, it is prohibitive.

Another point I would make is the desirability of, as far as possible, using oil sands instead of gas sands for storage of gas, because in the oil sands we have so much residual oil that we would like to get out that we can combine some of the operations of the gas storer and the oil-extractor by utilizing the oil sands, for the extracted gas carries a load of gasoline vapor. So I should say, first of all, see if it is feasible to get an oil sand before making use of the gas sand for storing gas.

The Anglo-Persian Company had an excess of residual oil that was so heavy they could not find a suitable market for it. They did not wish to burn it if they could help it and they determined to store it underground. But in one point they made a serious mistake. They stored it in a dry gas sand. When they go to take it out there will be a large amount they can not get out. What they should have done was to use a part of the oil sand that was most exhausted and turn the oil in there; then they could get it out with very much better recovery.

W. A. WELDIN:† I wonder if the difficulties of the peak-load in gas transmission could be obviated to prevent any great displace-

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†Blum, Weldin & Co., Pittsburgh.

ment of coal by gas for heating in places like the central and western cities for instance, because of the cost, if this large capacity storage is not possible. If in order to meet the peak demand the pipe-line capacity is used only a few days in the year and the cost of piping a long distance is taken into consideration, surely these long-distance pipe-lines can take only a very small part of the total full load to displace coal only to a small extent. I wonder if some of the gentlemen could give some idea of what the pumping costs of these long distances are.

D. P. HARTSON: The last part of the question is rather difficult to answer, but I can say that the very same thing can work still further in regard to coal. These pipe-lines, once they have been installed, must be operated indefinitely to protect the investment. In many cases they have gone out and offered gas at very low rates to industrial users in order that they may have an income to meet carrying charges. In some cases, I understand, this gas is sold at a price below the average cost of gas in order that it may bring in a revenue to pay carrying charges on the investment. In fact, the matter of obtaining a summer load or an off-peak load to offset the high demands made by domestic users in winter is very much of a problem.

J. D. SISLER: In answer to the question of cost of transporting natural gas, I know they are figuring on 38 cents per thousand cubic feet for transporting gas from Texas to Chicago.

D. P. HARTSON: On what load-factor is that based?

J. D. SISLER: Based on 75 per cent. of capacity. The belief that they have a market for both industrial and domestic gas is the reason for that load-factor. The distance is approximately 900 miles.

D. P. HARTSON: We know that the load-factor for domestic customers is somewhere between 30 and 50 per cent., and it is usually considered that the house-heating load-factor is not over 30 per cent. Even if you have considerable industrial sales with a load-factor of 80 to 90 per cent., your general average load-factor for the year will be brought down by the sales to domestic consumers.

SOME ECONOMIC PROBLEMS OF COAL*

By George H. Ashley†

This audience need not be told that the coal industry is in distress; nor does it need to be told that this distress dates far back of the present business depression. Coal-mining is only one of many lines of productive industry that in recent years has acquired a productive capacity far in advance of present consuming capacity. During the last century the market demands for coal increased so rapidly that the tendency toward over-production that followed each period of good times was soon absorbed. The curve of production began to flatten with the turn of the century, and during the past 10 years gives evidence of contracting instead of expanding. From 1918 to 1926 the curve, though irregular, was about flat. But since 1926 it appears to have taken a definitely downward trend, a trend which, as I pointed out in this city two years ago, I believe is likely to continue for several years, probably five or ten. This probable continued decline is the outstanding fact to be faced in any discussion of the present coal situation.

As a measure of this decline, from 1926 to 1929, bituminous production declined 41,000,000 tons, and anthracite 8,000,000 tons, and this notwithstanding a general industrial expansion. The industry is not in equal distress in all parts. Thus, as between 1918 and 1928, expressed in millions of tons, Illinois dropped from 89 to 55, Indiana from 30 to 16, Maryland from 4 to 2, Ohio from 45 to 15, Pennsylvania from 178 to 131; but West Virginia rose from 89 to 132, and Kentucky from 31 to 61. But in the last year or two the distress has become general, and promises to become more common.

Taken as a whole, as I shall point out later, the bituminous coal industry has a potential capacity about double that of the market demand, with the result that, on the whole, its capital, its personnel, and its plant are working only half time.

The decline in the market for coal is due to many causes, but of these three stand out prominently:

1. Increasing efficiency in use.

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2. The change from steam derived from coal to motors using gasoline for transportation.

3. The change from coal to fuel-oil and natural gas for heating and power production.

It is necessary to examine the facts in each of these lines, especially with reference to the outlook for the future.

First let us see what the efficiency engineer has done to the coal industry. In 1913 bituminous coal in Pennsylvania sold for an average of $1.11; in 1918 the average price was $2.59. It is generally recognized that this great advance in the price of coal was largely responsible for the activities of the efficiency engineers during the last twelve or fifteen years. Be that as it may, the fact remains that between 1919 and 1928 there was a reduction of 25 per cent. in the coal used per thousand gross ton-miles in freight service; of 18.9 per cent. in passenger service per unit; of 45 per cent. in the coal used per kilowatt-hour in steam-electric power-plants; of 14.6 per cent. in coal used in iron making per ton of pig-iron. In the instance of iron making, this loss is a total loss, as the number of tons of pig-iron produced in 1928 is almost identical with that produced in 1918 or 1923. That passenger revenues on the railroads have fallen off over $414,000,000 between 1920 and 1928 shows how little efficiency gain there has been compensated for by increased rail movement.

There has been a large increase in the use of power, but while power derived from oil and natural gas more than doubled between 1918 and 1928, power derived from bituminous coal fell off more than 10 per cent., and, taking account of the increased efficiency, the amount of coal used fell off still more. Looking to the future it may be noted that the average electric power-plant still uses twice as much coal per kilowatt-hour as the most efficient plants. It may therefore be anticipated that there will be a steady replacement of old and less efficient plants by more efficient ones. Furthermore, there is a steady drift from power derived from private power-plants making power at the point of use, to purchased power, usually with a large gain in efficiency. That spells a reduced market for coal. Were it not for the increasing use of oil and natural gas for power, including oil in the Diesel engine, it is probable that the growing demand for power would more than offset the increased efficiency in the use of coal. As things stand, however, it looks to me as though increasing efficiency in

the use of coal will for some years more than offset the growing demand for power made from coal, and that, therefore, the power market for coal is likely to decline rather than rise.

The change in transportation methods from rail to automobile, bus, truck, and airplane is tied up with present low cost and facility in use of oil and may be treated as one phase of the competition of coal with other materials. Every week brings news of more rail lines being abandoned. The use of air-conditioned cars in summer might help the railroads and the coal industry.

Next let us turn to the problem of the competition of coal with oil and gas. First, let us recall that the production of petroleum more than doubled between 1918 and 1923, and increased by more than one-third from 1923 to 1929. Second, 85 per cent. of the production of petroleum comes from three states—California, Oklahoma, and Texas. In those three states, with governmental aid, oil production has been pro-rated and reduced until it is estimated that the actual production is about one-half the capacity of the wells. That means that the industry is prepared to supply any increase in market demand not only for this year but for several years to come. Third, with the steady improvement in the appliances for the burning of oil and gas, eliminating many of the disadvantages and hazards of earlier equipment, their superiority over coal becomes more pronounced. Thus, the production of fuel-oil and gas oil has risen from 211,000,000 barrels in 1920 to 448,000,000 barrels in 1929, the latter amount replacing over 100,000,000 tons of coal. This is in addition to the market lost to coal through the steady trend from rail transportation to automobile, bus, truck, or airplane using gasoline.

Meanwhile, natural gas has been entering the coal market on a large scale and threatens to make still more extensive inroads in the future. For several years natural gas in the Southwest has been a drug on the market. Indeed, there were local markets for only a small part of the gas being obtained in those fields.

Pipe-lines have recently been constructed, or are under construction, to Denver, Wichita, Kansas City, New Orleans, St. Louis, Omaha, Memphis, El Paso, Salt Lake City, Chicago, Minneapolis, and way-stations, with side-lines to points off from the main lines. It is even proposed to utilize old pipe-lines in Pennsylvania to transport natural gas from western Pennsylvania and West Virginia to eastern

Pennsylvania and Atlantic Coast points. Some of the pipe-lines mentioned are in operation; others are under construction. The effect on the coal industry can well be imagined. The amount of natural gas produced and used in the United States more than doubled between 1920 and 1929, in the last year being equivalent to 74,000,000 tons of coal. When it is realized that the new 24-inch pipe-line to Chicago will deliver 200,000,000 cubic feet of gas a day (equivalent to 8000 tons of coal), and that it is only one of several lines now building, one gains some idea of what the coal industry faces. It will be a year or two at least before the full effect of these new lines will be felt in the coal industry. In the eastern natural-gas fields the threatened decline of a few years ago has been stayed at least temporarily, and the gas companies are seeking new outlets for their gas. I happen to know of one recent instance where the change from coal to gas brought one of the gas companies a contract for $4,000,000 a year, representing a corresponding loss to coal.

Competition from water-power is not keen, and it is not likely to increase greatly, though one large power-plant is now building on the Susquehanna at Safe Harbor, Pa.

On the whole, competition of coal with other natural fuels is increasing due to the overproduction and consequent low price of those competing fuels and their facility of use, and does not give promise of any immediate relief of pressure. Undoubtedly in time the pressure from these sources will decline and coal return to its own, but present prospects for such a decline within the next ten years are not bright.

A growing industry is always in a happy condition. An industry facing declining markets always faces difficulty. Just how difficult a situation the coal industry faces will be obvious from a few facts. It must be remembered that there are two sides of the problem to be overcome; first to reduce productive capacity to meet market demand; second, to keep it there in the face of almost unlimited unmined coal seeking a market.

In 1923 the bituminous coal industry had a productive capacity of nearly 1,000,000,000 tons annually, or about double the present demand.

There are 6450 commercial mines and 2600 operating companies (listed in the "Keystone Coal Buyers' Catalog") spread over 32

states. Considering for the moment only the area east of the Mississippi, coal underlies 127,967 square miles. The estimated reserves in that area are 860,000,000,000 tons, contrasted with less than 30,000,000,000 tons mined out and lost to date.

In 1928 there were 682,831 men employed in or at the coal mines of the United States, including Alaska. The average daily output per man, including anthracite, was 4.10 tons. Had all of these men worked 300 days, the output for the year would have been 850,000,000 tons, or 44 per cent. in excess of the actual needs which were met by the mining of 590,000,000 tons. This takes no account of many mines that have given up the struggle, but are ready to re-enter the arena the moment they can be run with profit. It has been estimated that, with these dormant mines, the coal-mining capacity of the country is double the present market demand.

We then face the following conditions:

1. Active capacity, say 40 per cent. above market needs.

2. Developed, potential capacity 100 per cent. above market needs.

3. A body of available undeveloped coal which can enter the struggle at any moment, amounting to, east of the Mississippi River only, 2000 times the present yearly production.

4. A total of 680,000 men employed an average of 206 days (1928), when 500,000 employed 300 days a year could supply the same amount of coal.

5. A constitutional provision that no man may be deprived of the lawful use of his property without due recompense.

What is the answer? The first step is to reduce the cost of coal. It may be answered that the cost of mining coal has already been reduced to the point where it yields neither a living for the miner nor any profit for the operators. However, so long as coal faces the keen competition now before it from oil and gas it must give serious consideration to sale price.

In this connection there are several factors that should be given careful study. First of all, let me say that reducing wages is not a way out. I quite agree with your fellow townsman, S. A. Taylor, that coal miners are an integral part of the coal industry, and any proposed solution for the industry's ills that does not insure to the

coal miner a good living wage equal to that in other related industries is no solution at all.

Continuous operation may yield a good living to the miner and reasonable profits to the mining companies, when the same mining rate and sale price, if the mine works only two days a week, will yield the miner only a starvation wage and no profit to the mining company. Every mine has a certain amount of fixed charges independent of production. Double the production and the fixed-charge-cost per ton of coal is cut in half and the difference may make all the difference between profit and loss. It is stated that the labor cost of a ton of coal at the mine now is about 70 per cent. of the total. That leaves 30 per cent. for cost of materials, capital charges, and salaries. Interest charges, taxes, and salaries paid by the month or year, are the same whether the mine works two days a week or four days. A given wage rate when the miner works but two days a week may not support him, much less his family, while the same rate for five or six days a week may give him a good living wage. In many mines time is an element, as, for example, where roof conditions change with time.

I would say, therefore, that the first step towards decreasing the cost of coal is to bring the production for any given plant as nearly to 100 per cent. of its capacity as possible.

Many mines are handicapped by excessive capital costs. I wish to speak especially of two of these. The first is the item of royalty, or of cost of coal in the ground, if purchased. I have never seen any discussion of the fair relation between royalties and profits. Looking back twenty or thirty years to the time before conditions were upset by the World War, I believe it is fair to say that profits always exceeded royalties or the corresponding capital cost of the coal in the ground. In general, I believe the average profits in those days ran at least three times the royalty, and in some places ten times the royalty. In other words, where the profit on a ton of coal was 30 cents or more, royalties were usually ten cents or less. This relation of course did not hold for all districts nor for all of the mines in any one district. Inquiry in other lines of industry brings the general response that royalties for raw material should not be over one-tenth of the average profits. To-day, while royalties have changed little or tended upwards, profits have faded away. It is true there have been local adjustments downward, but few that are comparable to the decline in

profits. We may, therefore, well ask ourselves whether it may not be time to ask for a readjustment of royalties on the basis of present conditions in the mining industry.

What is true of royalties is true of prices of coal lands. Remember that with interest at six per cent. and taxes at one per cent.—a total of seven per cent.—a dollar will double in 10¼ years, and quadruple in about twenty years. If, therefore, the coal in a given tract of land will require 40 years to be mined out, the estimated cost of the coal at the time it is mined will average four times the original price per ton. The original cost per ton may have been fair, or low; but, by the time the coal is mined, that cost may have become excessive in relation to profits. There is no help under present conditions for those who have purchased coal lands.

Closely related to the preceding is the practice of many companies of accumulating large reserves. Such reserves, though purchased at nominal prices, in time multiply the original cost. For example, the cost of coal held 100 years, computed at only six per cent. for interest, taxes and other costs, will be multiplied 339 times. Many companies are carrying a reserve of coal that is proving a mill-stone about their necks. What can such a company do with its reserves? Better let them go for taxes than that the company be sold out by the sheriff.

I have touched on only two items of capital cost that need careful consideration and possibly readjustment, if such readjustment can be made. In these days of diminishing profits, a careful study of personnel and salaries may sometimes prove profitable. It is sometimes found that with the closing of mines a $25,000 man is being employed and paid to run a $10,000 mine.

It is not my purpose to go into the technical study of the underground mining costs. To do that would unduly lengthen this paper. I will, therefore, leave that to the underground mining engineer and confine myself to the surface. I assume that all of you are familiar with the great savings now being effected by the mechanization of mines. From time to time the question is raised whether the future may not see some very fundamental changes in our methods of mining coal, such as the use of the wire saw so successfully used in the slate quarries of Pennsylvania, or the conversion of the coal in the mine into gas and the piping of the gas to the point of use. The writer

made a study of this question in 1898 and concluded at that time that coal-car transportation was cheaper than pipe-line transportation. An investigation now might change the figures.

Returning to the surface, or assuming that we have stayed on top, there remain the costs of preparation, sale and delivery. Experience seems to show that careful preparation more than pays its cost, particularly in these days of intense competition. This is a buyer's market, and it has been found profitable to please the buyer. Since writing this it has been my privilege to inspect a new $4,000,000 plant for cleaning coal, showing what one company is doing to meet present conditions.

In the matter of sale and delivery of coal, the greatest opportunity of saving, as conditions are at present, is through a rigid classification of coal and the pooling of sales agencies, and the delivery of coal to the nearest market. A large group representing producers, consumers, and the general public, is struggling over the problem of coal classification under the guidance of the American Standards Association. Assuming that the work will be successful, coal can then be sold under guarantee of meeting a certain classification covering composition, size, impurities, and any other quality that may enter into its use or value. This would permit pooling for purposes of sale and distribution. During the World War it was found advantageous to zone the consuming areas and specify where the supply of coal for each was to come from. In the future the coal industry may do the same thing in the interest of lower transportation costs. So much for reduction of costs.

A second possible, if not probable, way out is through improvement in the use of coal so as to meet the competition of oil and gas in the matter of convenience and cleanliness in use at lower cost. The anthracite industry and individual companies in the bituminous field have been carrying on research along the line of the better use of coal. The conversion of coal into gas to facilitate its use has long been practised. Some progress has been made towards grinding coal to dust and mixing it with a small amount of oil and a jell-making substance which would enable it to be transported and used as oil is now. Mechanical devices for the feeding of coal and the automatic removal of ashes are being studied; indeed, much has already been accomplished in this line. In the anthracite industry complete servic-

ing of homes is in effect, so that the owner's only labor is writing a monthly check. So far, most of the equipment offered is expensive to buy and operate, and so does not give coal a sufficient cost advantage to lead users away from oil or natural gas. When one sees what has been accomplished in some other industries through research, one wonders if the coal industry is doing all that it can in establishing and maintaining research in the use of coal.

Now we come to the hardest nut of all, the elimination of too much competition in the coal industry itself. Coal differs from some other raw products. The number of its uses is very limited and all finally end in its use for the production of heat by burning. Part of it undergoes an intermediate transformation into coke or gas, and undoubtedly in the future it will be used in the production of oil. The use of coal for the production of oil is out of the question in the United States as long as oil is being produced from wells as cheaply as it is to-day. The use of manufactured gas has been growing, but, in view of the extensive program of piping natural gas to consuming centers, it is probable that the amount of coal needed for gas manufacture will decrease in the next few years. The amount of coal used in the production of coke declined from 85,000,000 tons in 1918 or 84,000,000 tons in 1923 to 74,000,000 tons in 1927. From this, and what has previously been said, it is obvious that the coal industry can not hope to overcome internal competition through increased markets as it did during the last century.

There remains only one solution, the elimination of mines until those left will, when working full time, just meet the market demand with enough margin to cover peak periods or local shut-downs. Three things are needed:

1. Ways and means of stabilizing the industry so as to spread the demand evenly over the year.

2. A method of eliminating the surplus mining capacity with the maximum justice and the minimum of loss and distress.

3. A method of preventing the opening of new mines until need or advantage can be clearly shown.

I shall pass over the question of seasonal stabilization and confine attention to the elimination of surplus mining capacity and to keeping down that surplus.

England, faced with the same problems—problems that affected seriously one-eighth of her population—has passed a series of laws culminating in the Mines Act of 1930. Without going into detail, this provides for a Central Council and district boards, whose duties range from granting rights to work minerals, to fixing minimum selling prices, approving or dictating marketing schemes, fixing maximum production for districts and mines, and so on. There are, also, a Reorganization Commission, dealing with the amalgamation of collieries (if the owners fail to amalgamate within six weeks), a Coal Mines National Industrial Board to deal with labor problems, and national and district committees of investigation, composed half of consumers and half of operators and miners, to protect the consumer.

Space does not permit going into detail, but obviously England has taken the bull by the horns and provided not only the legal sanction but the machinery for such combinations as seem necessary, and for all other matters affecting such problems as marketing, opening new mines, selling prices, hours of labor. The Central Council allocates a maximum production figure to each district, and the district boards allocate tonnage to the individual mines, subject to changes as needed. The whole plan is flexible. The cost of administration is levied on the districts.

It may be worth while also to notice what several state governments are doing to help the oil industry help itself. We may take one example. Oklahoma in 1915 passed a law giving the Corporation Commission the power to make rules and regulations to prevent the waste of crude oil and the power to determine what constitutes waste. The state supreme court has ruled that the power given the Corporation Commission for regulating and restricting the use and enjoyment by land owners of the natural resources of the state, such as oil, so as to protect those resources from waste and prevent an inequitable taking from a common source, does not infringe the constitutional rights of citizens. The court quoted from a decision of the United States Supreme Court on a case from Indiana that "proprietors within the gas field all have the right to reduce to possession the gas and oil beneath. They could not be absolutely deprived of this right which belongs to them without a taking of private property. But there is a coequal right in them all."* Therefore, the state may

*Ohio Oil Company vs. Indiana, 177 U. S., 190.

restrain any one from taking or wasting an undue proportion "to the detriment of others or to the annihilation of the right of the remainder." The Oklahoma court held that under the Act the Corporation Commission might not fix the market value of oil. The case has now gone to the United States Supreme Court. This case bears only remotely on the case of coal, as coal is not "fugitive" as is oil or gas, but "stays put" until it is mined. It does, however, emphasize the point that personal rights under the Constitution may not jeopardize the coequal rights of others, or the rights of all by methods that lead to waste or loss.

It is my understanding that these recent drastic laws in England were based on the social welfare of the large class of miners, rather than on questions of property and profit.

The problem in this country, I need to reiterate, presents two distinct phases which should be kept clearly in mind. First, the reduction of productive capacity, both mines and miners, to meet only market needs, taking account of all possible improvements in mining methods, preparation and marketing; second, the restricting of new mining development until need can be shown. There has been a great change in opinion within the coal industry within recent years. Before the World War, if my memory serves me aright, the coal industry was petitioning for governmental aid, and that was not the first time the industry had been in distress. Then came the war and the industry was put on its feet again, and for some years felt quite competent to manage its own affairs. Again competition both within and without the industry is resulting in distress for all involved; and again sentiment is turning toward government aid of some kind.

On the one side are those who feel that the industry would get on its feet if certain restraining legislation were so modified as to permit the forming of large associations or corporations and to permit these associations to form a national body with power to allocate production, and centralize and control distribution and marketing. On the other side are those who feel that the public is not in a mood to permit such combinations and powers without governmental authority and control, and that, judging by the failure of certain recent efforts at consolidation, the industry itself would not be able to form such combinations or associations without governmental assistance. Having in mind the success the Federal Reserve System has had in stabiliza-

tion in the world of finance, one wonders if some of the same fundamental principles might not be applied in stabilizing industry. Certain it is that no such scheme could be applied without the individual industrialist being compelled to submit to some curtailment of his freedom of action in order to obtain the advantages to be derived from united action of the whole group.

I have no specific plan to offer, but I believe that the problem of reducing the mining capacity of the country to meet market demand can be met only by some central organization, council, committee, or board, which will have not only power to propose a plan of action, but power to carry out its plans. It is barely possible that following President Hoover's suggestion, changes may be made in the anti-trust laws which would permit the organization of such a board or council within the industry, possibly with members representing the government and the consumers. Failing that, I see no way out except some such system as is being tried out in England.

Then comes the question of how the opening of new mines may be controlled. Remembering the difference in the taking of coal from the taking of oil and gas, and that coal is not taken from a common reservoir, there are those who question whether restriction of the opening of new mines can be carried out legally unless the government recaptures and owns the coal in the ground.

Let us see what might be involved in undertaking to control the opening of mines in tracts of unmined coal. Granting that a coal land board for the purchase of coal in the ground were set up, its first job would be to work out a plan of procedure that would as nearly as possible be automatic in its application, and be fair to the present owners, yet would involve the least possible cost to the public which must ultimately pay the bill.

Some idea of the magnitude of the job is realized by those who have had anything to do with valuing coal on the public domain, where, for each 40 acres, account had to be taken of the character and quality of the coal, its thickness, section, acreage, depth, distance from railroad, and any other known factors that might affect its cost of mining or value when mined. But there would be this difference—public coal lands were priced on the assumption that they were to be purchased to be mined out immediately and continuously in rather small units. At the present rate of mining, nine-tenths of the recover-

able coal east of the Mississippi will not be touched in the next 100 years and four-fifths will not be touched within the next 200 years, and therefore has no present value. But who shall say which coal lands will not be touched in 100 or 200 years?

A question naturally arises as to what such a project would cost. For the purpose of this study let us confine our attention to the bituminous fields east of the Mississippi River. The area of coal lands in that district is 127,967 square miles, or about 82,000,000 acres; the estimated total tonnage of coal is 860,610,000,000 tons or roughly 10,000 tons per acre (say 7500 tons per acre) of recoverable coal. The number of mines in 1928 was 4880, and production that year 453,000,000 tons.

If all of this coal paid a royalty of 10 cents a ton, the aggregate value the day it was mined would be $61,500,000,000. That is one extreme. At the present rate of mining it would take 1366 years to mine out all of this coal—an average time of 683 years. What value to-day has 10 cents to be collected 683 years hence? None. That is the other extreme. The actual value lies somewhere between, depending on the estimated time until the coal is to be mined, and on the rate at which the coal is recaptured.

Assuming that the rate of mining remains the same as to-day, and that values are based on an average royalty of 10 cents a ton, with interest at six per cent. and taxes at one per cent. to be compounded annually, if the government should buy to-day the coal to be mined during the next 20 years (9,000,000,000 tons), the cost would be $450,000,000. Suppose after 20 years, production increased to 500,000,000 tons a year and remained there indefinitely. To buy to-day the coal to be mined from 20 to 40 years from now (average 30 years) would cost $150,000,000 (a 10-cent royalty 30 years from now is worth only 1.5 cents to-day). Under the same conditions the coal to be mined from 40 to 60 years from now would be worth to-day only $40,000,000; that to be mined between 60 and 140 years from now, amounting to 40,000,000,000 tons, would be worth to-day only $45,000,000, and $15,000,000 would amply cover the value of all coal not to be mined under 140 years from now—a grand total of $700,000,000. To allow for some higher royalties suppose we take $1,000,000,000.

Were the government to issue bonds for $1,000,000,000 at three per cent., interest and principal could be taken care of by a tax of 25 cents on each ton of coal, to be reduced 1½ cents each year. The bonds would be paid off in about 15 years. It doubtless could be figured out so that the tax and the indebtedness disappeared together. The plan naturally raises many legal as well as economic problems, including the matter of future taxation of coal lands after recapture.

Some of the disadvantages of this plan as I see it are as follows:

1. It puts an extra financial burden on the coal industry and the public at large at a time when outside competition is throttling that industry, and when reduced selling price is most necessary if it is to meet that competition.

2. Under the plan suggested for governmental recapture of coal, the bulk of the coal in the ground is rated as having no present value because of the long time before it can be mined; but the determination of what coal may be mined within a reasonable time and what may not, presents great difficulties; and it will always be hard to convince a man who has been paying taxes on coal in the ground that his coal is of no present value and therefore should be transferred to government ownership without recompense.

3. To carry out the recapture plan would involve a very high overhead expense for the necessary surveys, estimating tonnage, transfer of titles, and all the rest, and cover many years.

4. When the coal in the ground shall have been recaptured it is no longer taxable by state or county.

I still have up my sleeve one other proposal that I believe is completely feasible and that may avoid some of the difficulties of the recapture plan. It may be called the "deferred-tax plan." In this plan, coal having been declared invested with public interest as a conservation measure, all taxes on unmined coal are deferred until the coal is mined and are then levied on the coal *in the ground* by bed and acre as the coal in any bed and acre is proved by actual mining. At the same time, in the interest of conservation of a limited resource, the government would assume the right to control or license the mining of coal and through proper boards or committees could allocate the tonnage to be produced in any state, and pro-rate the tonnage to be produced at any mine.

Some of the advantages of this plan, which of course is not new, are as follows:

1. It would lighten the burden of all operating companies, all of which are carrying the burden of taxation on their coal reserves.

2. The deferred-tax plan could be put into operation at once, and could, in the main, use existing organizations, notably the United States Bureau of Mines and the several state departments of mines, with their personnel of mine inspectors and the mine maps now required by law.

3. Under the present tax plan, owners of coal lands pay taxes on the coal in those lands possibly for a century, while they may be getting no income from the coal. By the deferred-tax plan the tax is paid when the coal is being mined and sold, and therefore is bringing in money from which the tax may be paid.

4. By the deferred-tax plan the general scheme of local taxation is not distributed; that is, while local or state taxes may be deferred, they are ultimately returned when the coal is mined.

5. The principle of deferred taxes is already in use in Pennsylvania in connection with private forest lands, on which, under certain conditions, taxes are not paid until the timber is cut. Louisiana, under a constitutional amendment, levies a severance tax on all natural products, including minerals. The right of taxation is no longer questioned. It would require a constitutional lawyer to determine whether the state or local authorities have the right to rebate taxes as here proposed without a constitutional amendment, and whether, if taxes were so rebated or deferred, the government might thereby acquire the right to control the mining of the coal, including the power to issue a license to mine, to restrict output, and so on, or whether these powers might not be obtained on the ground of the general welfare as previously suggested.

Taking account of all of these facts and factors, including the outstanding fact, as I see it, that the coal industry will face a steadily declining market for some years, it seems that, if the industry is to get on its feet in the near future, probably some such procedure as the following must be adopted (I am drawing on English experience):

1. A declaration by the national government that coal is invested with public interest, which withdraws it from the control of the anti-trust laws of the land, and permits government co-operation

in its conduct. It may be asked why coal-mining should be invested with public interest, rather than farming or lumbering, or many other industries. Following English precedent, such action might be based on the ground that the social welfare of several million people—the miners and their families—was paramount to the rights of owners of coal in the ground. Coal is one of man's most valuable assets and the amount of it is definitely limited. When our oil and natural gas are exhausted there will still be a large body of oil-shale. When the oil-shale is gone there will still be some coal. When the coal is gone the last of the world's known hydrocarbons is gone. We will still have sunlight, wind, and wave and tide, which will supply all man's need of power; but sunlight is to coal as maple sap is to maple syrup; a gallon of syrup is worth a barrel of sap. Furthermore, it has not yet been shown that lubricating oil or gasoline can be made from sunlight. Therefore, it behooves man to look well to his use of coal to see that it is not used wastefully or wasted in mining.

2. Having declared coal invested with public interest, the government must either so modify the present anti-trust laws as to permit the coal industry to organize so as to re-establish itself on a paying basis, or it must grant legal sanction and establish governmental machinery for such a re-establishment of the industry.

3. In order to prevent such a re-established industry being again wrecked by the opening of new mines, it has been proposed that the government recapture the coal in the ground. An alternative is here offered in the suggestion that the government might acquire the necessary power of control through the plan of deferred taxes.

Finally, if an attempt be made to carry out any of these plans, it is my own thought that existing agencies should be utilized as far as possible, and that governmental control should be limited to the minimum amount necessary to accomplish the end sought.

DISCUSSION

J. F. Robinson, *Chairman:** We have designated one or two persons to enter immediately into discussion of this paper. That does not mean that others are not free to enter into it. We feel that the benefit derived from these meetings comes very largely from an open discussion, and after Mr. Weldin has presented a formal discussion we shall be glad to have any one here enter into further discussion.

W. A. Weldin:† Dr. Ashley has courageously given us the facts in the economic situation of the coal industry and made suggestions that should prove most valuable to all who would strive to understand the true situation and in the light of the facts do what may be done to improve the situation.

I do not think that I can contribute anything substantial either to Dr. Ashley's paper, or to the information of this audience—which includes engineers and operating men much better informed than I am—unless, by way of emphasis upon some of Dr. Ashley's points, I may add a little.

I have plotted a few curves showing progression of the factors mentioned.

Fig. 1 is that curve of coal production with which we are all familiar. How proudly we published it during those early years when output was doubling every decade. I would call your attention to the fact that this geometric rate of increase ceased, not after the World War, but about 1910. By 1914, the diagram indicates how far production was below what it would have been if it had gone on doubling every 10 years. (See curve 1-a in Fig. 1.)

I wonder if it is merely a coincidence that the years 1890 to 1910 include the period of formation of the great "trusts." Perhaps this was a period of wasteful expansion which was followed by a turning of the attention of industry to better organization with its attendant economies, and especially to research.

It is a fact that Robert Kennedy Duncan brought to Pittsburgh from the University of Kansas his unique idea of university research for the benefit of industry in the year 1910. On this idea was founded the Mellon Institute, which in 1911 started its smoke investigation

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†Blum, Weldin & Co., Pittsburgh.

and in 1916 began research on heat insulation. At the same time the larger corporations were engaging in research programs.

In 1909, while employed by the H. C. Frick Coke Company in the design of new beehive coking plants, I was told that the United States Steel Corporation had decided to build only by-product ovens, and we changed our half-finished plants to coal-shipping operations.

I judge that it was more than a coincidence that about that time began the nefarious work of the efficiency engineer, of which Dr.

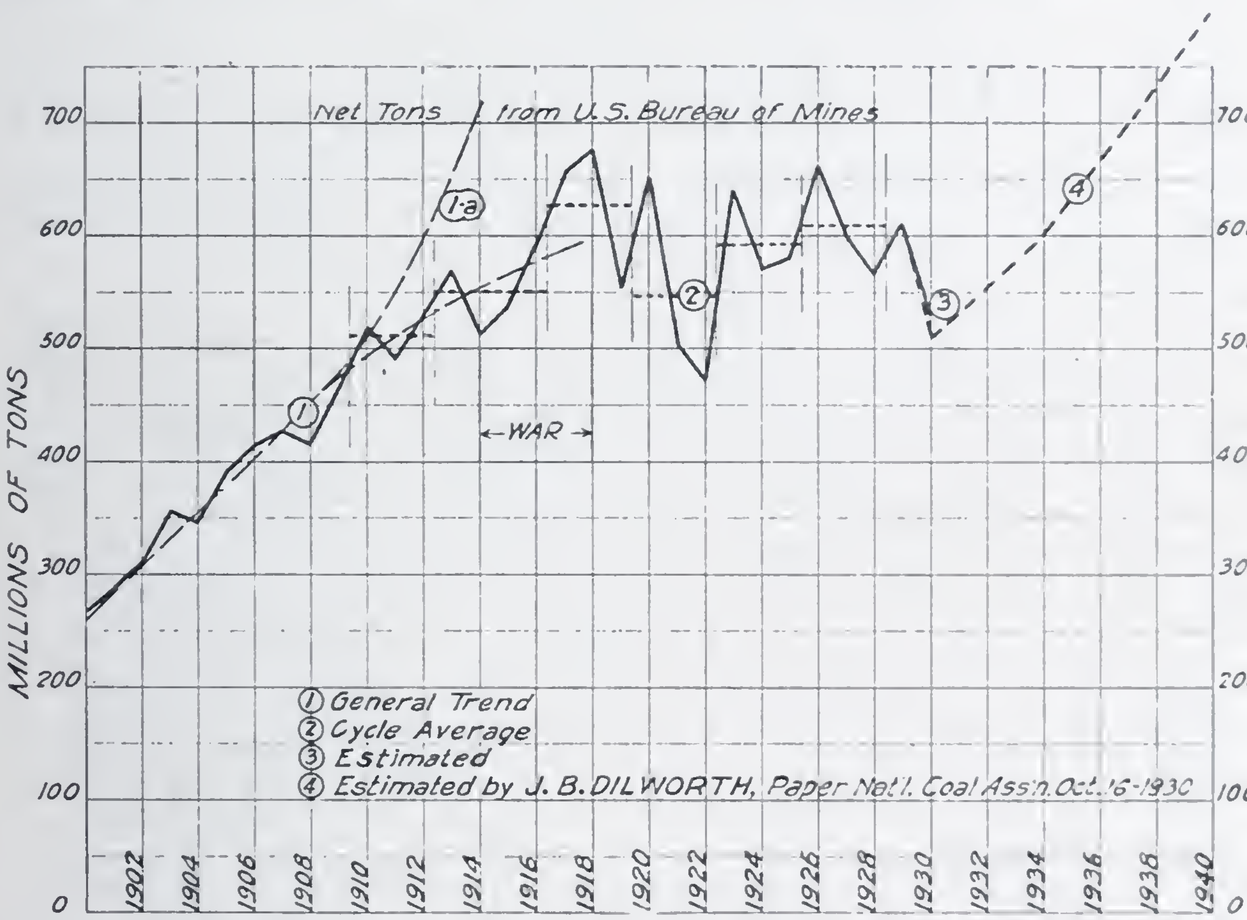

Fig. 1. Total Coal Production of the United States.

Ashley speaks. The effects of the World War, however, so obscure the trends as to make such speculations somewhat doubtful. It is to be observed that there is a similar flattening of the curves for iron and steel and railroad ton-miles for the period 1910-1914, which would suggest business depression. It may be that if there had been no war, all of the curves would have resumed their upward flight. Certain it is that the war stimulated research and economy, and that the engineer acquired prestige which enlarged his scope.

The statement that economy of use is what has prevented increased consumption recently is well shown, I think, by the contrast between the coal curve and the curves for iron, steel, railroad ton-

miles, and manufactured goods. Since all are rising rapidly except coal, it follows that industry is getting decidedly more product without using much, if any, more coal. Other fuels are neglected in this comparison, but I judge that even if they were reduced to a coal equivalent and added to the coal curve, the latter would still be very flat in comparison with the others.

Another feature of the coal curve at once strikes the eye. Since the year 1914 it is highly serrated. That these peaks and valleys are caused by the "business cycle" is suggested by the fact that the same years were marked by similar ups and downs in the other curves shown on the following pages. This cycle seems generally a short one, about three years in length. It is not to be confused with the major movements indicated by the recurring depressions such as 1921 and 1930.

It is interesting to divide the graph into periods so as to include one peak year in each, as indicated in Fig. 1, and compare these periods by averages (dotted lines numbered 2). This seems to indicate that the stimulation due to the war was compensated for by a following "low," after which increased production is indicated. Of course the present cycle is incomplete and therefore can not be counted upon. It will probably show a low average on account of widespread depression, but for that very reason it is not typical and therefore would not help to indicate the trend, even if we knew its average. Some writers seem to infer from this economy of use that there is actually less coal burned now than formerly. This is certainly not true as to any comparison with pre-war conditions, and if we make allowance for the abnormal war demand and ignore 1930 we can say that the country is now using as much coal as—or more than—it ever did.

No, the trouble is not that there is no business, but rather that the selling price is ruinously low. No doubt this is due to fierce competition within the industry, among units with a combined capacity far beyond present needs. This excess capacity is not due simply to a heedless building by the industry, a policy of opening new mines, regardless of the need. On the contrary, the present capacity would be necessary for present needs if fundamental conditions had not changed. In 1926, the Coal and Coke Committee of the American Institute of Mining and Metallurgical Engineers demonstrated,

in its annual report, that the coal industry was no more over-developed than the steel industry or the copper industry.

What happened was very well put, I think, by Mr. Francis, of the Island Creek Coal Company, at the recent hearing of the Lake Cargo case before the Interstate Commerce Commission. He stated, in effect, that until very recently the excess capacity was prevented from being a great factor in the competitive situation by two things—labor troubles and the car shortage. He quoted H. L. Findlay, President of the Youghiogheny and Ohio Coal Company, who testified before the Senate committee that prior to 1923 the coal-mines were limited to a 50 or 60 per cent. car supply, which is now practically 100 per cent. Mr. Francis also called attention to the strikes, in the union fields, which formerly acted in the same direction, but which are no longer a handicap in most of the former union territory. As far as Pittsburgh and Ohio are concerned, some of the mines have only just opened after expiration of the Jacksonville agreement. In other words, what is now excess capacity was, prior to 1923, capacity necessary to produce the country's requirements under the then existing conditions. Then the same part of the capacity which is now excess was prevented most of the time from competing, so that it did not depress the price so much. Now, the entire national capacity is unleashed and the struggle to keep mines running results in a rather even distribution of the business over all districts, resulting in shorter running time for all mines and unrestricted price competition. There seems no alternative but to suppress the excess capacity. Indeed, much of it is bound to be lost in spite of any efforts to hold it effective. How far this elimination has already gone is suggested in some studies my office has recently made. The number of mines in the Pittsburgh district as listed in the "Keystone Coal Buyers' Catalog" dwindled from 322 in 1925 to 217 in 1929, a loss of 32.5 per cent. In the Ohio field, No. 8, the reduction was from 174 in 1925 to 97 in 1929, a loss of 44.3 per cent. On the Chesapeake & Ohio Railroad, in Southern Ohio, 78 mines were listed by the state as officially abandoned from 1923 to November 1930. In the Fairmont field, the directory list fell from 250 in 1925 to 190 in 1929, a loss of 24 per cent. There are not lacking those who say that the pendulum is about to swing too far and that the next boom may see an actual lack of capacity. As to the future of our coal curve, I am neither a prophet nor the son of a

prophet, but, nevertheless, there are some pointers to be dimly seen and I might use a little paper upon them, even if only on the basis of "fools rush in."

F. G. Tryon and H. O. Rogers, of the United States Bureau of Mines, in a paper on "Analysis of the Consumption of Bituminous Coal in the United States" at Carnegie Institute of Technology,* divide the total consumption of bituminous coal into 10 categories. For our purposes we may lump several minor ones under general manufacturing and combine coke-ovens with steel-works, which will give us the following, based on statistics for 1926:

	Per cent.
1. Railroad fuel, including not only locomotives, but all uses of not only Class I roads, but (by estimate) all steam roads	27.7
2. Coke-ovens and steel-works	21.4
3. Electric utilities	7.7
4. General manufacturing	23.9
5. Domestic and all other	19.3
	100.00

The last category includes heating of large buildings other than factories and unseparated items as water-works, construction, United States Navy, and small plants not covered by the Census of Manufactures.

Railroad fuel, the largest item, seems to hold the greatest threat, for, as Dr. Ashley truly says, there has been a reduction in nine years of 25 per cent. in coal used per 1000 revenue ton-miles on Class I railroads. However, due to the increase in the total ton-miles, the falling off of actual consumption has been much less. If the reduction continues at the rate indicated as the recent trend (dotted line 5 in Fig. 2), the coal industry will lose by 1940 some 15,000,000 tons of annual production, which is about 10 per cent. of the railroad consumption, but only about 2½ per cent. of the total production of coal in the United States. This trend depends, of course, on two factors—the total operations of the railroads, and the economy of use. As to

*Proceedings of the Second International Conference on Bituminous Coal. 2v. 1928. Carnegie Institute of Technology, Pittsburgh. (See v. 1, p. 139.)

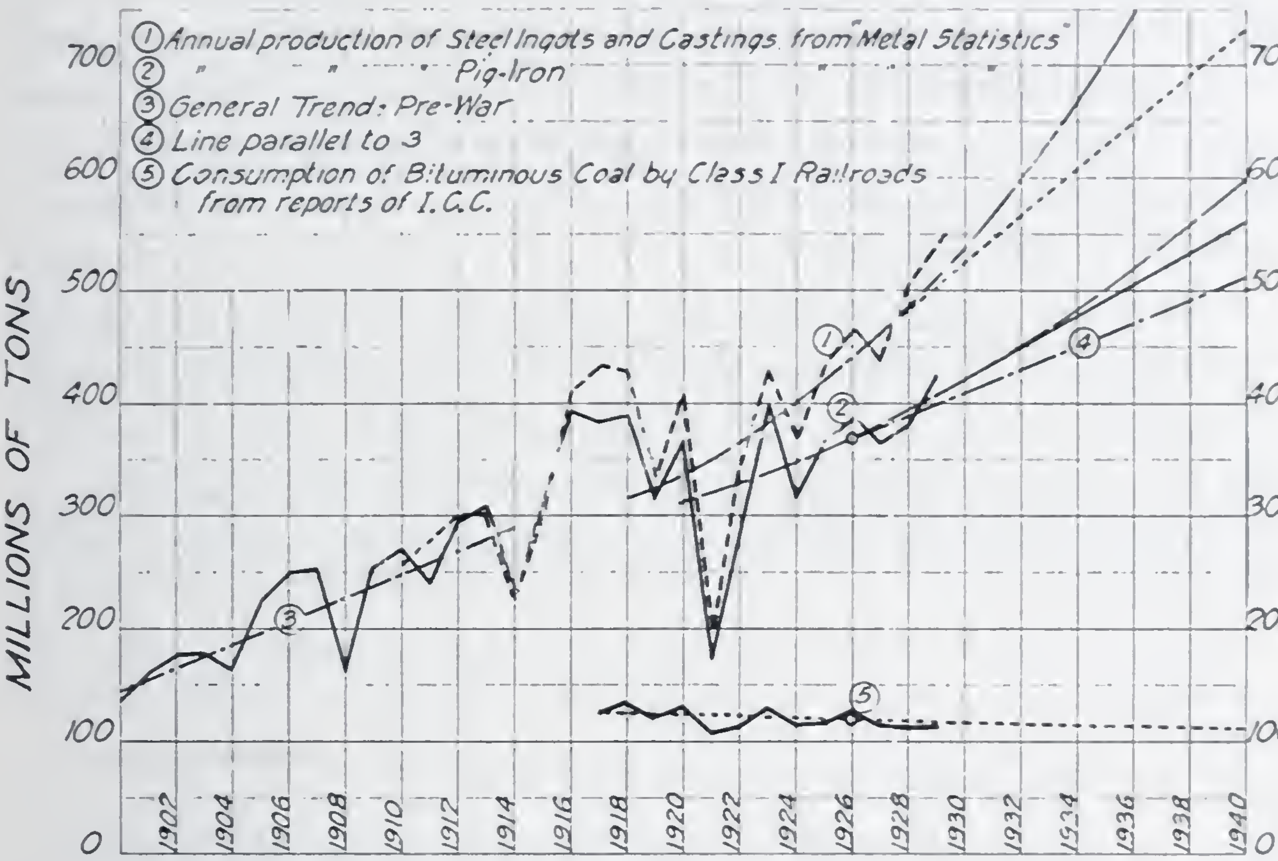

Fig. 2. Statistics of Coal and Steel Industries.

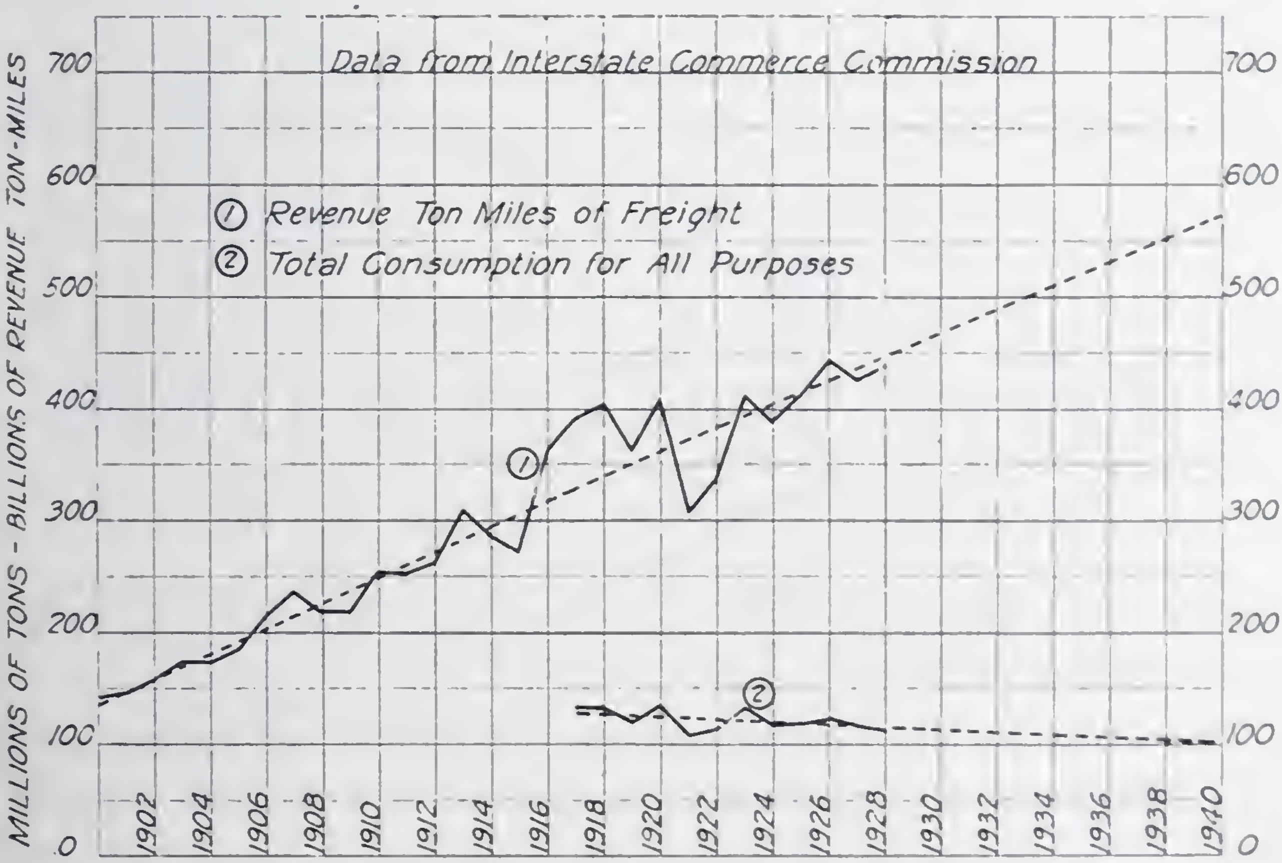

Fig. 3. Consumption of Coal by Railroads.

the former, there is nothing in the curve representing revenue ton-miles of Class I railroads (Fig. 3) or value of manufactured goods in the United States (Fig. 4) to indicate that, so far at least, we have approached the saturation point for goods, or that the competition by motor vehicles and waterways has seriously reduced the total performance of the railroads.

As to the trend of economy, one gathers from perusal of the *Proceedings of the American Railway Association* that future savings in locomotive performance will be harder to attain. The past economies have been made largely by training firemen and by applying to the engine such well known devices as feed-water heaters, super-

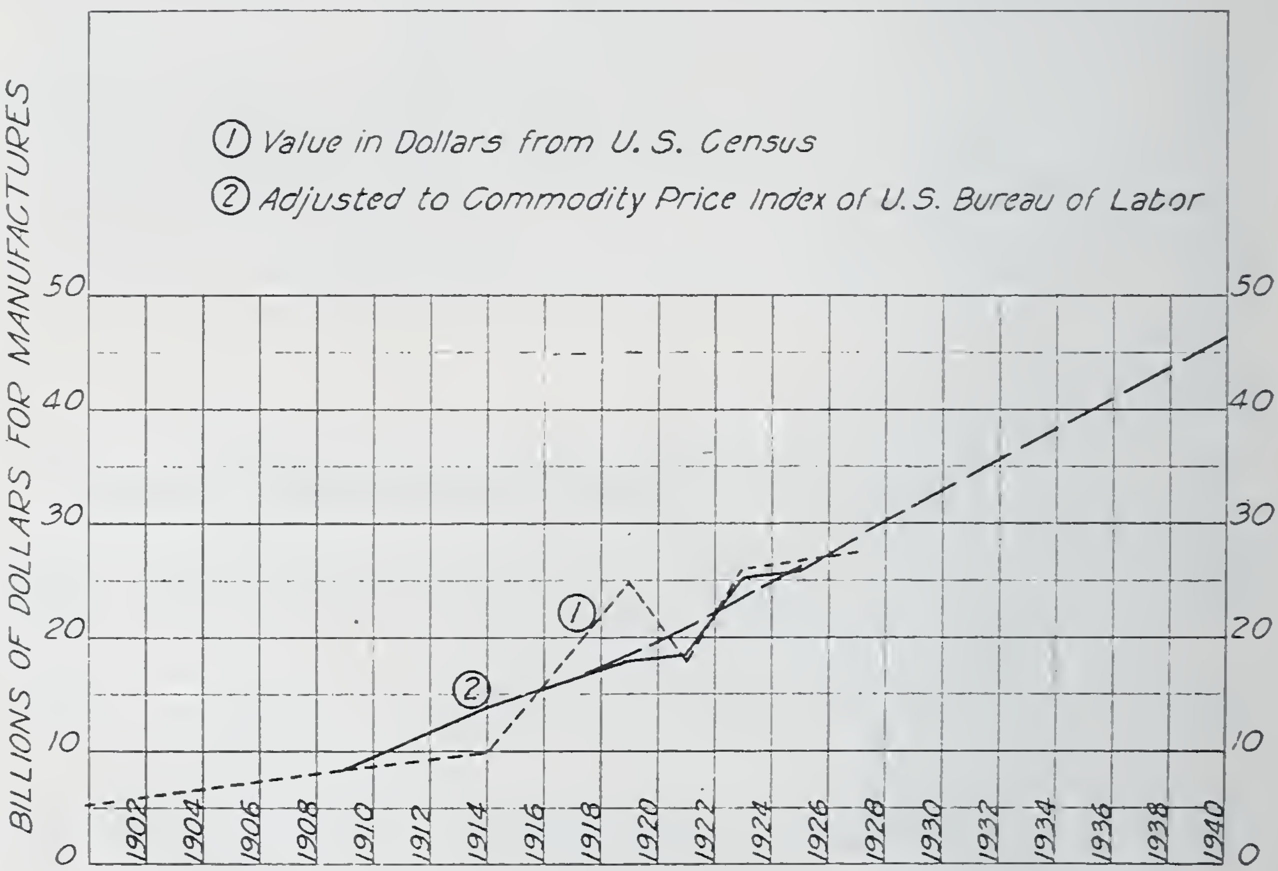

Fig. 4. Value of Manufactured Goods in United States.

heaters, and compounding, and by bringing the design of the boiler and furnace up to date.

It seems to me that this movement is largely an accomplished fact. Of course, further improvements are bound to come (for instance, roller-bearing freight cars), but these improvements, I think, will be of such a nature that they must come gradually and can not affect the whole problem much in the next ten years.

The installation of locomotive stokers is, I believe, intended as a move in the direction of saving labor rather than fuel. Perhaps this factor will increase rather than diminish the consumption.

It is doubtful in many minds whether further savings either in locomotives or power-plants (or even some that are current) are justified in view of the present low price of coal. Taking all of these factors into consideration, I think the actual railroad consumption is not likely to fall, at least not as rapidly as indicated in the next ten years; that is, the dotted line 5 in Fig. 2 errs, if at all, on the low side.

As to the steel industry, Dr. Ashley says that a net loss has been suffered here, as the production of pig-iron in 1928 is almost identical with that of 1918 and 1923. That is true, but I think that after due allowance has been made for the disturbing effect of the World War, and the post-war period of adjustment, the curve of pig-iron production really shows a decided rise (Fig. 2). Considering the trend of only the last few years, a concave curve is indicated. Perhaps it would be more conservative to draw a tangent to this curve, which would suggest a production of 560,000,000 tons in 1940; or, better still, one tangent at 1926 (line 4), which is the year selected by Tryon and Rogers for purposes of comparison.

It is interesting to note how the line representing steel ingots and castings diverges from the pig-iron curve. I suppose this divergence is due to the increasing use of scrap. Tryon and Rogers suggest, as the best measure of consumption by this industry, pig-iron plus half of steel. Such a curve would show a very decided rise.

According to the same authority, fuel economy in this industry has held total consumption to a slight decline in recent years, but most of the saving has been due to production of coke in by-product instead of beehive ovens. This change, so far as the steel industry is concerned, has been completed. Arthur D. Little, at the same conference, stated that the thermal efficiency of the oven is about 80 per cent., and therefore there is no prospect of any great saving of fuel in better ovens. Another factor in saving fuel has been the practice of charging hot metal from the blast-furnace into the open-hearth furnace. This movement has also been completed. The turning from Bessemer to open-hearth practice offers little for the future. The latter was about one-third of the total steel in 1900 and is now about 84 per cent. Summing up all the factors, I do not see why the coal

consumption of the steel industry should not increase. Of course it is mainly captive tonnage, and may be more so.

Electric utilities show perhaps the most striking economy. It seems improbable, however, that the rate of improvement can long continue as at present. If it did, as indicated by the straight line on Fig. 5, the average plant would equal the present best in about ten

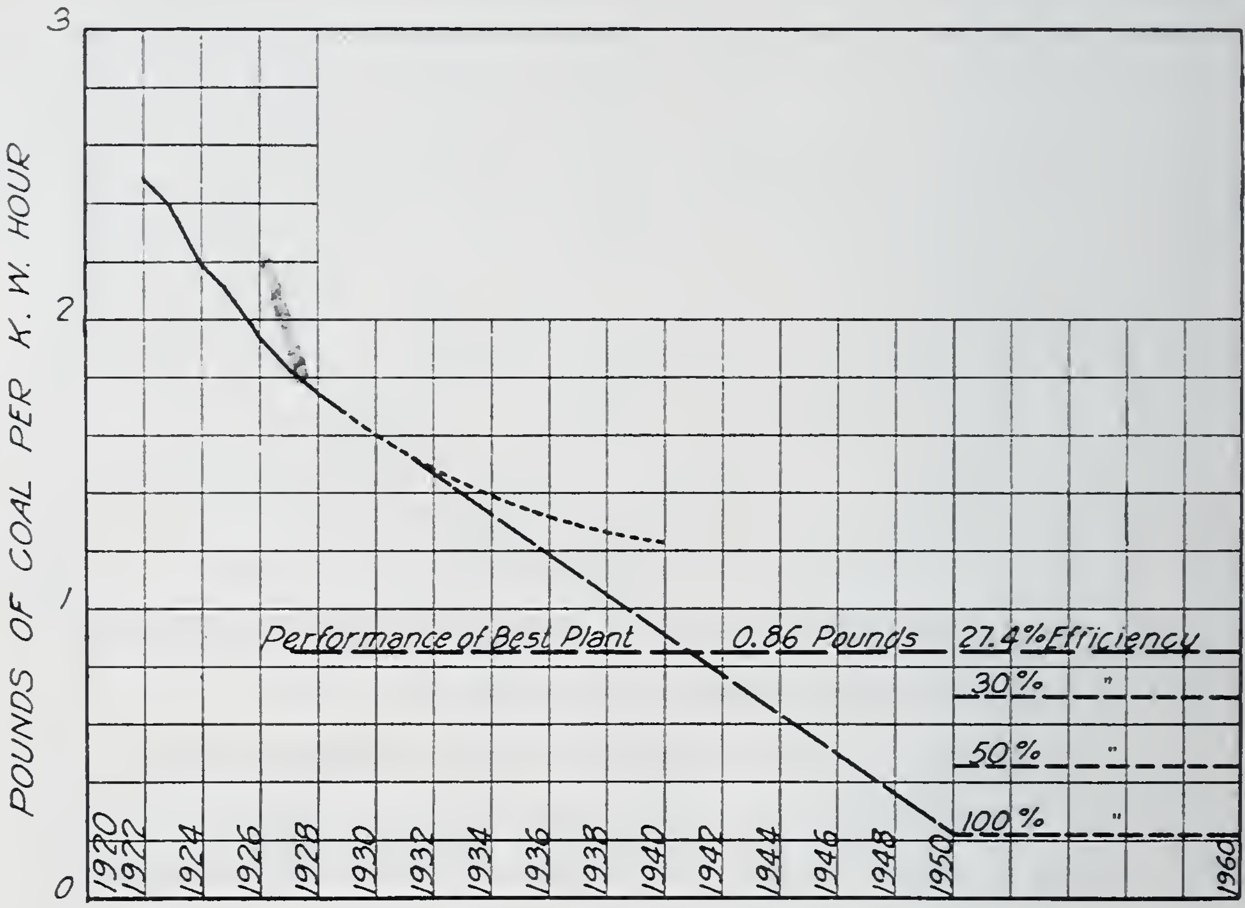

Fig. 5. Trend of Efficiency of Public Utility Electric Power-Plants.

years. Such wholesale displacement seems too radical. In fact, the actual progress is rather a concave curve, as indicated in the upper dotted line. This seems logical as, of course, the easier won economies are instituted first, and later efficiency is obtained with increasing difficulty and at constantly greater expense. In view of the low cost of coal, the process must be under a heavy handicap at present. While the overall thermal efficiency seems to allow lots of room for improvement, when it is remembered that the losses represent all thermal and frictional losses whether in furnace, boiler, stack, prime mover, condenser, or elsewhere, it is evident that high efficiencies are impossible. Even if entirely new apparatus, such as the mercury boiler, comes into use, it would seem physically and financially impossible for it to supplant any substantial part of present equipment in a few years.

In Fig. 6 these same curves have been converted to a smaller scale for comparative purposes. The departure of curve 2 from curve 1 indicates the growth of water-power. It is my idea that under present conditions water-power is not likely to increase. Curve 1 has therefore been assumed to resume its upward direction next year at its recent rate and curve 2 to be parallel to it. The part played by oil and gas is indicated by the difference between curve 2 and curve 3. Curve 4 indicates power developed from coal as a percentage of that

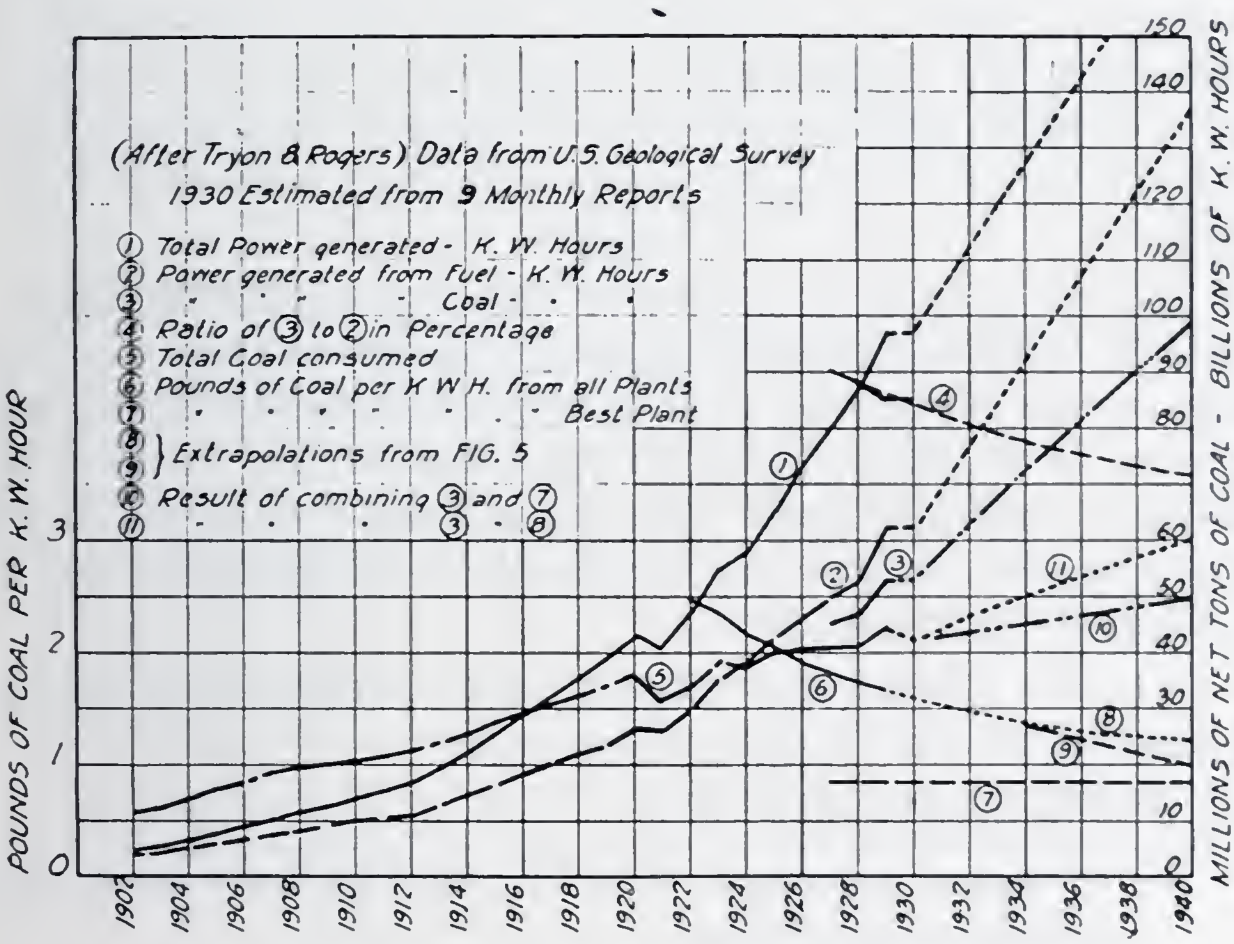

Fig. 6. Trend in Consumption of Fuel by Public Utility Power-Plants.

derived from all fuel. I have assumed that it will continue to fall as indicated. From this assumption comes the continuation of curve 3. Those who differ from the above view regarding water-power (for example, Arthur D. Little and R. V. Kleinschmidt*) generally think that oil and gas will play somewhat less of a part, so that perhaps there is sufficient allowance between curves 1 and 3 for all these factors.

*Proceedings of the Second International Conference on Bituminous Coal. 2v. 1928. Carnegie Institute of Technology, Pittsburgh. (See v. 1, p. 110.)

The curve extending the total coal consumption is simply the product of curve 3 and curve 8 or 9. If any one thinks the assumptions are not sufficiently conservative, the effect of any change in any or all of them can easily be seen from the graph. I do not believe you are likely to make any changes which will depress curve 11, for instance, below the level. In other words, I see nothing in the statistics to indicate a loss in consumption, but everything to suggest an increase. General manufacturing, as was developed at the above mentioned conference, has shown a steady consumption. Increases due to greater volume of manufactures and greater consumption by "heat" industries (brick, glass, etc.) have been offset by reduction in fuel consumed to produce power. This saving has been largely from loads transferred from private plants to the more economical utility plants.

It would take more of a prophet than I to forecast the developments in this field, but I should guess that the known factor of recent great increase in volume of manufactured goods would have the most influence on the result. I should suppose that here, as elsewhere, the obvious economies have been made first and that future gains would be at a reduced rate, and that therefore the total consumption will at least hold level if it does not rise.

The last classification, "Domestic and all other," is involved in so many factors that I can not see any trend.

On the one hand there are:

1. Increasing population (Fig. 7), requiring more houses and buildings of every kind.
2. Cooling and air conditioning, now a fact in many buildings and some railroad cars. I suppose it ought to be adopted at once in the better residences and in office and other buildings. The rapidly growing industrial South might adopt cooling and create a large new demand for coal.
3. The newer technique of refrigeration of foods, which may become a factor in increased consumption of coal.

On the other hand, we know very well how extensive is the displacement of domestic coal by oil, gas, and by-product coke. It is rather humiliating to contemplate the inroads of oil brought from a distance upon the domestic market right in this city, which has coal

within its own limits. But of course there was no organized resistance to this invasion. This brings us naturally to Mr. Ashley's next topic, competitive fuels and water-power.

The oil industry, like the coal industry, is said to be suffering from excess capacity, excessive competition, and too low prices; but as it is more homogeneous and better organized than the coal industry, it seems probable that it will recover first. If oil prices are due to recover at all in the immediate future, the economy factor will in

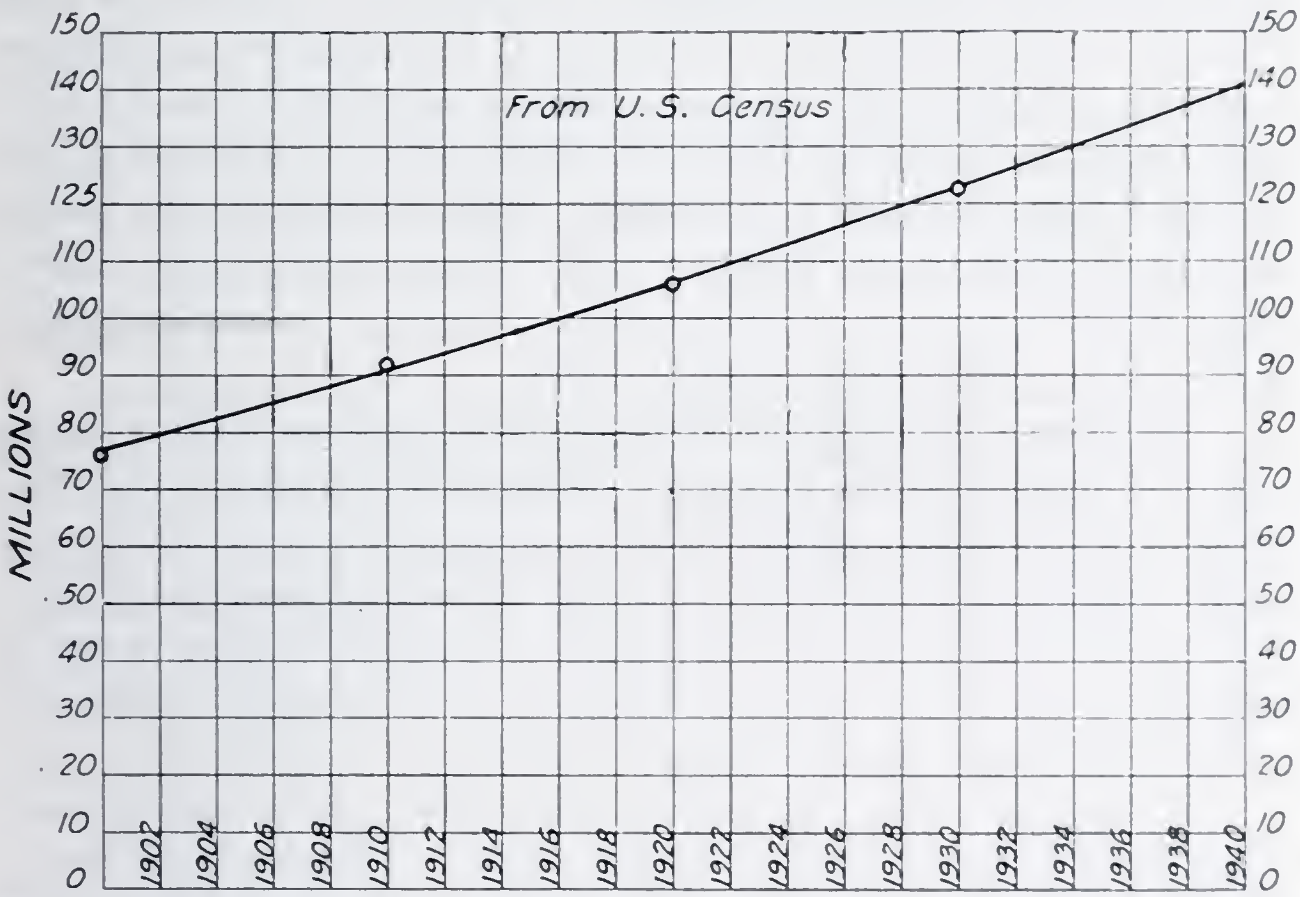

Fig. 7. Population of the United States.

many instances favor a return to coal. In fact, I think domestic oil burners, at least around here, are put in, not to reduce the cost of heating, but to avoid the dirt and nuisance of firing coal and handling ashes. Now, that we are finding out that oil is dirtier than coal, or at least dirtier than coke, I think that much could be done by the coal industry in developing domestic heating apparatus that would be easy to operate, automatically regulated, and with a net cost which, at least in many parts of the country, would make oil unattractive.

Most of the house-heating furnaces I see are no better than the one I fired as a boy, when it was said that the "horseless carriage" would never be a practicable vehicle. I have in my home a furnace

(the first in Pittsburgh) which is a partial solution, and I have seen practical stokers, but nothing I know of in regular use goes far enough. An organized drive such as suggested by the Anthracite Institute, coupled with provisions for complete service of the coal-burning furnace, ought to relegate oil to the background in this field.

With gas the case is different. It must be admitted that gas is the ideal domestic fuel. Still, right here in Pittsburgh, where we produce both coal and gas, it appears that one must pay dearly for the convenience of heating with gas. It is hard to see how these long lines are to pay if they are to depend on a heating load. Probably only those which have a business mainly commercial, giving a high load-factor, will succeed. This will still leave the great bulk of the heating business to coal or its products. The statement of Mr. Hartson, of the Philadelphia Company, here to-day in discussing another paper, that they use the entire capacity of their lines only *one day a year,* throws a great light upon the matter.

Whether a diversion of domestic use from coal to by-product coke will increase or decrease coal consumption is doubtful. Perhaps, by reason of a better balance of the various products, the steel companies will increase their output at the expense of something else—for instance, sell more coke for domestic use, or increase ovens to keep up the supply of furnace coke and use the resulting increase in gas to displace coal now used under boilers.

In any case, use of by-product coke tends to take business from commercial mines to give it to captive mines. I judge that the domestic consumption is bound to decrease, but such reduction is apt to be slow because your typical householder is conservative and it generally costs money to change fuels.

Water-power has possibilities. Little and Kleinschmidt say our streams can develop 10 times as much power as is now used. However, I am told that most of it can come into development only after coal becomes much more expensive, and that there are actually very few remaining sites where water-power can be developed economically under present conditions.

In Fig. 6 the divergence of curves 1 and 2 measures the development of water-power by the utilities. It is significant that 1929 showed no increase in water-power. Water-power is not so significant anyway. Tryon and Rogers, in the above quoted paper, credit it

with 6.3 per cent. of all energy developed. Firewood developed 5.5 per cent. I suppose this wood is mainly that used in producing charcoal iron. Still, the United States Geological Survey says that half of one per cent. of the public-utility electric current comes from firewood.

Summing up all those factors, it seems to me that tendencies are all in favor of slightly increasing consumption in the next few years, or at least in favor of no permanently reduced demand. I do not have the data on which to base a conclusion like the one arrived at by Mr. Dilworth (Fig. 1).

There will still be a market and there will still be a coal industry, which will have to put itself on a stable basis. I presume the shoe industry and the baking industry do not consider that a doubling of the consumption of their products every 10 years is essential to their prosperity.

It seems to me that a strictly engineering approach to the problem is necessary. The present movement towards mechanization and other forms of modernization is in the right direction. After all, coal loading is the last stronghold of the ancient way of doing heavy repetitive work by hand. No doubt we shall see rapid introduction of machine mining, incentives in methods of pay, new subdivisions of tasks, better control of labor, multiple shifting, etc. I judge that this movement will bear favorably on all phases of the present trouble.

First, it will speed the elimination of excess capacity, because many mines will not lend themselves well to it. If the program reduces costs radically, such unadaptable mines will be "out of luck." Second, the reduction of costs will permit a frontal attack on competing fuels. Third, I think it will tend to meet the fear that, even if stabilization can be reached upon a profitable basis, prices will again be forced down by the rash entering into competition of new mines opened on the strength of such favorable prices. I think that, whereas heretofore it has been rather a simple thing to open up a small mine, in the future only those can compete who can invest great sums and wait a long time to organize a highly specialized force. Such enterprises are not so likely to enter the field unless the situation justifies additional capacity in the long run.

I think that there has been a good deal of misunderstanding of the savings in overhead costs due to increased output. In the first

place, it does not always follow; increased production frequently means a corresponding increase in equipment and in supervision. In the second place, capacity is often confused with output. It seems trite to say that if more cars, more mining machines and more foremen and clerks are put on to increase the peak output without increasing the average output, the overhead costs will go up instead of down, yet so great has been the impression of the years of mounting demand on the minds of some operators that they are still suggesting economies based on increasing their output without knowing whether the coal can be sold. Indeed, I suppose there are cases where even a net reduction in the annual output would spell economy, if the reduced tonnage, representing a less competitive market could be produced by a steadier flow from the mine, and hence with reduced equipment, less overhead, and better supervision.

I do not see any appreciable new markets for coal due to low-temperature carbonization, hydrogenation, etc. The figures on costs, etc., given at the Second International Conference on Bituminous Coal do not bear examination, and it is impossible to see the commercial possibility of such processes except in special localities. At such places, they will merely displace other processes with little change in total consumption. Changing coal into coke, tar, and gas still leaves it fuel, and the loss of heat value in the process is made up, I believe, in efficiency of burning.

I can not see any great tonnage being extracted as chemicals. These would come from the tar, and 99 per cent. of such tar is now burned. Any large-scale increase in tar production would simply reduce the percentage of chemical use to the vanishing point.

As to help from the government, that seems to me hope based on illusion. It is true that the government is organized and the industry is not; but the government is organized on a popular representative plan. I think such organization is fundamentally incapable of such constructive (even creative) contribution as we need. It was intended to be so. Our fathers had their eyes fixed on the danger of oppression which accompanies concentration of power and so dissipated it (I think) deliberately to the point of inefficiency.

I fear that our government can never efficiently regulate the opening of mines, keep competition within bounds, and arrange a fair price to producer, consumer, and labor. Every experience demon-

strates this, whether it be an attempt to fix prices, to prevent large combinations, to run railroads, to furnish water to a large city, or to clean the streets of a small village.

The government can restrain the strong and ruthless for the benefit of all, and this is its necessary function, but it is too bad when such restraint must be applied, for it is blighting. Let the government withdraw its hand, remove the restraining laws preventing the proper organization of the industry, and cease trying to build schools and roads out of coal reserves. These reserves are only potential wealth and so no proper subject for taxation. They do not participate in government. They need neither police protection against theft, fire organization, roads into them, nor schools over them.

I suppose some of our states will have to take back a lot of coal lands for unpaid taxes, as the owners are realizing that some of them can not be marketed for many years, so that their present worth is considerably less than nothing. This ought to demonstrate to at least a few taxing bodies that this kind of property does not represent a taxable value and that they had better remove the tax from such long-time reserves.

The papers in this issue were presented at the meeting or the dinner in commemoration of the Fiftieth Anniversary of the Society.

THE FIRST HALF CENTURY OF THE ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA*

By George S. Davison†

A half century of continuous activity that has been successful, honorable, and useful is well worthy of a celebration. This is the semi-centennial of the Engineers' Society of Western Pennsylvania; its golden jubilee. A great thrill comes to the few of us who, to-night, are permitted to look back over that magic period of fifty years and recall to mind the many intimate associations with those who made loyalty to our Society an important part of their professional creed. The names of some of these are household words in this community, while a few of them, like Brashear and Fessenden, are known throughout the civilized world.

Pittsburgh in times past, and in the following order, has been known as the Coal City, the Iron City, the Smoky City, the Steel City; but the term we love best is the Workshop of the World. Providence has favored us with an inexhaustible supply of power in various forms hidden away beneath our rugged hills. This heritage has made our great workshop a possibility. Despite the scurrilous article that questioned the civilization of Pittsburgh, and which appeared recently in a magazine that once was decent, we thank God for the Scotch-Irish Presbyterians, to whom the article referred, and who settled here when our community was but a village. They and those who toiled with them and followed in their footsteps have made good use of the talents from Nature's great local storehouse.

While it might be difficult at this late day to point to any organized effort deserving of the credit for Pittsburgh's success, prior to the birthday of this Society, I doubt not that one of the important forces that have helped to maintain Pittsburgh's greatness in the past fifty years has been the Engineers' Society of Western Pennsylvania. A cross-section of its membership discloses chemists, biologists, metallurgists, and those who specialize in all the branches of engineering. As elsewhere, the engineers in Pittsburgh have in a large measure taken

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over the management of industry and transportation, which has added materially to their prestige.

For brevity's sake this Society might have been named the "Engineers' Society of Pittsburgh," after the style of local engineering societies in other cities. In selecting the longer name for it, those who were responsible wrote over its doors in large letters a welcome to all engineers. The propriety of the name, now perhaps better than then, is apparent; for of the more than 1200 members living in the metropolitan district of Pittsburgh, but half reside within the city's limits; and furthermore, the membership is found in 27 states and five foreign countries.

I am a native of Pittsburgh and, with the exception of a period of three years and my college days, I have spent my life here. It was during this three years' absence that the Society was incorporated. Returning a few months later I registered as a member, and so I have seen it grow from less than 100 members to 1700; from a wandering band with no fixed headquarters to the occupancy of the elegant and commodious quarters in this hotel. I have seen it scrape through on an annual expenditure of $800, while in these times its annual budget is $38,000. Of those who, with me, have enjoyed its membership for 50 years there are three—Robert Trimble, recently retired as Chief Engineer of the Central Region of the Pennsylvania Railroad; Thomas M. Rees, proprietor of James Rees and Sons Company, builders of steamboats and engines; and J. W. Walker, who, while having business interests in Pittsburgh, lives at Devon, Pa. All these gentlemen are present to-night.

Prior to 1880 several unsuccessful attempts had been made to form an engineering society here, but evidently the time was not ripe for such a venture. Looking back to those days and considering the conditions that surrounded the work and life of the engineer, one could realize that associations for the discussion of technical subjects had little appeal for him. His opportunities for service were few. The projects upon which he might be engaged were not large, nor did their completion add much to his professional reputation. His pay for services rendered fell short of being a *quid pro quo*. His spirits lacked that buoyancy so necessary for the full development of his genius. As an illustration of how the engineer felt toward his profession at that time, I may relate an incident. I had indicated to my

parents a desire to secure an advanced engineering education. Upon being told of my wishes, a prominent engineer acquaintance advised my parents against humoring me, he claiming that the profession of the engineer was decadent in this country. However, my persistence overcame his advice. Some years later I was at his heels as he joined this Society, and later I shared the high honors of the Society with him. He became an optimist and died a rich man. As for me, I have no regrets.

But whatever the causes that postponed its formation, we know the Society was formed on January 6, 1880. On that date 50 members were enrolled and at the end of the year the number had been increased to 85—that is, that number had accepted membership and paid their dues. Of this 85, only about half (42) could have qualified as engineers. I am told that, as of to-day, the Society has a membership of 1659, of whom about 1500 are engineers—certainly a splendid increase. The second half of the first year's membership was made up to a considerable extent of the coal barons and iron-masters of the community, and their assistants. To name a few of the more important, there were such names as Jones, Laughlin, Kloman, Park, Nimick, Painter, Singer, and Moorhead. There were Andrew Carnegie, his brother Thomas, and their partner Henry Phipps, who died within the past few months and who gave the Phipps Conservatory to Pittsburgh. Then there were B. F. Jones, George McMurtry, Joshua Rhodes, John Ricketson, Reuben Miller, W. P. Snyder, George Macbeth, James Hemphill and many others of less fame than these. A few of the engineers who were then, or who afterwards became, prominent might be mentioned. There were Samuel Rea, late President of the Pennsylvania Railroad; Samuel Felton, who until recently was Chairman of the Board of the Chicago Great Western Railroad; Edwin Thacher, the designer of the slide-rule that bears his name; and popular "Bill" Jones of the Edgar Thomson works of the Carnegie Steel Company. Then there was gallant Capt. A. E. Hunt, who led Battery B upon the field of San Juan in the Spanish-American War. We see him now as he sat astride his horse the night he left Pittsburgh for the front. We remember the sad faces of his engineer friends as he returned stricken unto death with fever. His name will always be associated with the aluminum industry, as he gave it the first real boost. He was the

President of the Society when we held our first banquet in 1892. The program reprinted on the menu card of to-night is a reminder of him and of the first banquet. Then there was Ed. Bigelow, the father of Pittsburgh's park system. The foregoing list of names is confined to those who were of the first 50.

While I can not claim any familiarity with the work done in bringing the Society into being, in due course of time I had an opinion as to those who deserved the greatest credit for it. I would say that the foremost of these was James H. Harlow, the Society's first secretary. Then there was William Metcalf, the Society's first president, whose influence no doubt secured the co-operation of industrial leaders. Thomas Rodd, assistant chief engineer of the North West system of the Pennsylvania Lines, interested the engineers in the service of the various local railroads. In this connection I would mention that old wheel-horse, T. P. Roberts, who not only wrestled with the men engaged in general engineering practice to get them into the Society, but who as a member set the record for attendance at the meetings and taking part in discussions.

In what I have previously said regarding the status of the engineer, I did not intend to imply that engineering thought and practice had not had their triumphs prior to 50 years ago. While S. F. B. Morse was known originally as an artist, yet his conception and practical demonstration of the telegraph, 90 years ago, entitle him to be classed as an engineer; his contribution to science was, in fact, an engineering feat of the greatest importance. The first overland railway was completed in 1869, which event more than any other brought a harmony of ideals and purposes to the people of this country. George Westinghouse had conceived his idea of applying compressed air to the braking of trains, so that in 1868 he equipped the first passenger train with his air-brakes in this city. The Hoosac Tunnel, the Eads bridge at St. Louis, and the Brooklyn bridge were completed about 1875. Alexander Graham Bell was born a Scotchman but became an American a few years before he exhibited his first telephone in 1876. By 1880, about one-third of the present main-track mileage of steam railroads (93,000 miles) had been built in the United States. By that time the country's coal deposits and ore fields had been thoroughly prospected and considerable areas had been opened up by the mining engineer. The art of extracting petro-

leum from its hidden pools by means of driven wells had been well advanced by the end of the Civil War. Water-power had been driving the looms of New England for several generations. Fully fifty cities, containing about forty per cent. of the population of the United States, were being served by public water-supplies before 1880, and, contemporaneously with these supplies, sewerage systems were built to some extent, though the building of sanitary sewers made little progress until after 1890, and the treatment of water by means of filtration was much later—in fact, filtration made little progress before 1900.

It was later than 1875 when the first pronounced call for trained engineers was made. Prior to that time there were not many schools in this country, perhaps a dozen, which taught a complete technical curriculum. And the enrolment of any one of these schools did not exceed three hundred. But immediately prior to 1880, there sprang up a demand for engineers. Congress decided to take an inventory of the country's navigable streams, its miles of sea front, its docks and harbors. The extension of the one existing transcontinental line caused a great rush on the part of promoters to build other such lines, and these projects were made easier of accomplishment because the Bessemer process for making steel rails had brought their cost to a satisfactory low level.

About 1880 the Lake Superior ore region was opened up to supply the increased demands of the blast-furnaces for raw material. The coal and coke industries had to be expanded to furnish the additional fuel for furnaces, mills and factories. Then came more railroads to haul the increased amount of raw and finished materials. More workmen were needed and the immigrants from Europe literally blocked our ports of entry. As these were assimilated, they had to be housed, clothed and fed. For these purposes the merchants stocked more goods on their shelves. When the shelves could not hold large enough stocks for their trade there had to be more building of warehouses and stores. The ground needed for the buildings so greatly increased in value that taller buildings were necessary. Then came the steel skeleton building, and more ore, more fuel, more furnaces, more mills, more workmen, more farms, more clothing, more factories, and more railroads. Then the manufacturers turned from natural cement to Portland cement. The scientists, who for thirty

years had been exhibiting the induction-coil as a plaything, woke up as to its practical possibilities, and with the dynamo the electrical age was born.

It was just as this grand procession of technical events was forming that this Society was born. But in advance of that birth a serious contention arose between two schools of thought among the leaders of those who held an interest in the profession. One side contended that an education in the underlying principles of technical knowledge was less important than the acquiring of that knowledge through practical experience. The others argued to the contrary. The argument waxed hot and lasted for years. Judging by the large number of students in engineering enrolled in all the schools and colleges of the country to-day, the school men gained their point overwhelmingly. There are about as many engineering students in one institution in this city at this time as there were in attendance at all the engineering schools of fifty years ago. And so during all that time the profession has continued to expand.

In 1880 the following national technical societies, the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Chemical Society, and the American Society of Mechanical Engineers (the latter organized in 1880) had a combined membership of 1922. The American Institute of Electrical Engineers was formed in 1884. In October of this year (1930) the combined membership of these five societies was 79,891, a forty-fold increase in 50 years. During the same period the population of the United States increased but 2.4 times. These figures do not accurately compare the total number of engineers with the population of the country, but from them it can easily be adduced that the engineer has made marvelous progress in the advancement of his profession, and has greatly improved his opportunities for service.

I take the opportunity at this time of recalling some of the conditions in Pittsburgh 50 years ago. The Monongahela Navigation Company, a private corporation, owned such locks and dams as made the Monongahela River navigable at all seasons of the year as far as Morgantown, W. Va. Daily, morning and night, packets handled freight and passengers throughout the hundred miles of improved river. The first dam on the Ohio River, then called Davis Island dam, was under construction and was the initial step of a program

that required fifty years to complete, namely, the canalization of the Ohio River. Pittsburgh was then the "Smoky City," for natural gas had not yet been piped into the city, although it was being used at the Spang-Chalfant mill in Etna and in the mill of Graff, Bennett and Company at Millvale (a mill dismantled many years ago). What is to-day the North Side was then Allegheny, the citizens of which, as each morning they looked across the river at their sister city, gave thanks to the Lord that "they were not as other men are." The population of Allegheny County by the census of 1880 was 355,869 as compared with the 1930 count of 1,374,622. The telephone system of this community in 1880, operated by the Central District Printing and Telegraph Company and using the Bell telephone, had 777 telephones in operation as against 232,208 on October 1, 1930. Wooden block pavements were laid in outer Penn Avenue and in Fifth Avenue from Oakland east in 1873 and 1874. Later some of the principal streets down town were laid with this block. Within ten years the city began to replace these pavements and they were all removed by 1890. For replacement block stone was used. Such other streets as were paved were surfaced with cobblestones, taken from the bed of the Allegheny River. The sidewalks were laid with building brick in herring-bone design, except where it was necessary to span the streets, in which case large sandstone slabs about eight inches thick were used.

The river bridge of the then most recent date was the Point bridge, built about 1876. It was of the iron eye-bar suspension type. It was recently replaced. The Smithfield Street bridge and the Sixth Street bridge were of the wire suspension type, the former replaced in 1883 by the present structure, and the latter followed in 1890 by a bridge which has been replaced by the present structure. The Union bridge at the Point (now called the Manchester bridge), the bridges over the Allegheny at Ninth, Sixteenth and Forty-third streets, and the Tenth Street bridge over the Monongahela were of wood, generally of the Burr-truss type, reinforced with wooden arches. The first bridge at Seventh Street was not built until after 1880. All these structures have been superseded.

Until 1879, Pittsburgh took its water-supply from the Allegheny River at the foot of Eleventh Street. The pumps of the plant, labeled "Samson" and "Hercules," were well adapted to gather from

the intake mud, sewage, waste oil from adjoining refineries, animals and fish, dead or alive. However destructive such a mixture was to the human organism, it had one advantage over the highly manipulated water of to-day, in that it was not so destructive to the water-pipes in the homes. Allegheny received its water hard by, near the present location of the H. J. Heinz plant. In 1879, the Pittsburgh plant was moved to Brilliant, where it became famous as the home of the Lowry engines.

In 1880 there were ten or a dozen independent street-car systems in the community with an aggregate mileage of about sixty miles, the motor power of which was the horse and the mule. In lieu of a taxi-cab service, the Excelsior Express Company operated buses (seats inside and on top) between the depots and hotels only. The Monongahela House was the fashionable hotel of the city. No little of its patronage was derived from passengers traveling on the Monongahela and Ohio River packets.

The artificial light of those days was derived from manufactured gas, kerosene, and candles. There was a limited area down town, where arc-lamps were used for the lighting of streets and some of the more pretentious stores. I first saw an incandescent light in 1883, using the direct current. Alternating current had not yet been developed. There was no Carnegie Library and no Schenley Park.

The local railroad situation in 1880 was about as follows. The Pennsylvania System had no by-passes by which it could, as now, avoid hauling its traffic through the city; so there was then no Port Perry bridge, no Ohio Connecting Railroad, no Brilliant cut-off. All interchange of freight traffic between the eastern, northern, and western lines was handled in the yards east of and adjacent to the Union station; and all through freight to and from the northwest system crossed Penn Avenue and Federal Street at grade. The Baltimore & Ohio Railroad had no extensions to the south or west of the city. The Pittsburgh & Lake Erie Railroad had begun operations in 1879 with its southern terminus at Jones and Laughlin's mill on the South Side. At the time of which we are speaking, the task of bringing all railroads in the country to standard gage had about been completed. The main line of the Erie Railroad from the east to the west was made standard. It might be interesting to know that the rail lines on the north side of the Allegheny River, now forming a part of

the Baltimore & Ohio Railroad, had been built originally narrow gage, and extended only as far as Butler and New Castle.

We were still living in the iron age. Tool-steel had been made for many years. Steel produced by the Bessemer and Siemens-Martin processes was quite new in America. Hark to the opening sentence of a paper read before this Society on April 20, 1880, by its author, a member of the Society, Albert F. Hill:* "Within the last few years there has been developed in this country a tendency toward steel construction which to-day is so pronounced as to command the most thoughtful consideration alike of constructors and manufacturers." Certainly a sound from the graveyard of dismantled puddling furnaces! While Mrs. O'Leary's cow in 1871 had kicked over a lighted lamp, in consequence of which a large part of Chicago had to be rebuilt, and a few of Chicago's architects in this rebuilding program resorted to skeleton-framed construction, skyscrapers were not attempted until 1886. Since then we have passed from the iron age, through the steel age, and are well along in the cement age.

It has been hinted in the early part of my address that this Society has been a wanderer. It may be interesting to hear to what extent this has been true, so I shall trace the organization from one to the other of its homes. For the first three months of 1880 its meetings were held in the office of the Secretary of the Western Iron Association, at 77 Fourth Avenue, just east of the present Stock Exchange. Joseph D. Weeks, Secretary of the Western Iron Association, an authority on the iron industry, was an ardent member of the Society and assisted materially in getting it off to a good start. From June 15, 1880, for four years, the Society occupied one of the rooms of the Mercantile Library Association on Penn Avenue near Sixth Street. The rent was $300 per annum, which sum, by agreement with the Association, was to be spent upon books of a scientific nature that were to be added to the Library. The use of the library was free to the members of the Society. It is my recollection that the quarters there became too small for our increasing membership, and interruptions through the use of the library by others became annoying. So another move was made by returning to the Western Iron Association rooms. By the way, while the Mercantile Library was a large and creditable institution, it went out of existence when the main

*Proceedings, v. 1, p. 106.

Carnegie Library of Pittsburgh was built. The Society later moved to the Germania Bank building on the corner of Wood Street and Diamond Street. At that time the Chamber of Commerce occupied this building and, as I remember, the Society was a sub-tenant of the Chamber. In April 1886 the Society went to the Irish building at 708 Penn Avenue. This building was razed a few years ago to permit of the building of the Stanley Theater.

Prior to 1891, the Thaw family, which had occupied the home still standing at the corner of Stanwix Street and Duquesne Way, moved to the East End. Beginning April 1, 1891, the Pittsburgh Academy of Science and Arts leased the large double parlor of this house, and the Society became a sub-tenant of the Academy. These quarters being on the first floor were easily accessible to our members. At that time engagements for the engineers hereabouts were plentiful and they were feeling the benefit of the new era that had come to their profession. These conditions made the Society popular, and it advanced rapidly in membership and with a great sustaining interest.

It was while in the old Thaw residence that the Society held its first banquet and gave its most lavish entertainment, lasting three days, to a large party of French engineers who were visiting the World's Fair in Chicago. While here, the important move of forming the Chemical Section was made. It was while occupying these quarters that the seeds of smoke prevention, water filtration, and advanced road building were sown, each of these subjects being fully investigated and reported upon by committees appointed for those purposes. The appointment of these committees was prompted by admirable papers by members of the Society.

Suddenly, almost over night, the Academy of Science and Arts and its sub-tenants were dispossessed of their comfortable home. There was insufficient time to look for a new home down town and, on April 1, 1894, the Society accepted an offer for rent-free quarters in the Carnegie Free Library on the North Side. The Society remained there two years. As the members considered this location out of the way, the interest and the attendance at meetings began to wane, and it was quite apparent that new quarters must be sought.

During this period of two years the Carnegie Library of Pittsburgh was completed in the Oakland section. That was in 1895, and some time prior to this date the Academy of Science and Art, some

of whose members were members of this Society, had proposed that all the technical societies of this community, under the leadership of the Academy, unite in accepting for joint use rooms and lecture halls which Mr. Carnegie had set aside in the new building for such organizations. A joint committee of the Academy of Science and Art and this Society was appointed to give consideration to the plan. The discussion of the question divided the Society into two camps and debate ran high. Those favoring the plan urged the great benefits that would arise out of free and permanent quarters. Those opposed pointed to the failure of the experiment with which the Society was still laboring—that of having quarters outside of the active business section of the city. It was urged that free rent would not compensate for the disadvantage. The latter sentiment finally won, and a long lease, dated April 1, 1896, was made on 410 Penn Avenue, at that time a private dwelling. With the lease went a short-term option for the purchase of this property. This option was allowed to lapse, as it was thought that even this property was too far away from the active business of the city. To save expense, only part of the building was used by the Society.

While at 410 Penn Avenue the Society again returned to prosperity. It remained here ten years, and on April 1, 1906, removed to the Fulton building, securing more commodious quarters there. Here it remained until May 1, 1910, when it removed to still better quarters on the twenty-fifth floor of the Oliver building. Then after a tenancy there of seven years, another forced and regrettable move had to be made. The Union Trust building was occupied five years; that is, from May 1, 1917, to May 1, 1922. At the latter date the Society moved to the quarters it now occupies in the William Penn hotel, where it has the advantage of a club without expense therefor, and in which it can hold meetings of any size up to 1200.

In what I have said I have dealt chiefly with the conditions before and at the time of the founding of this Society, in order that a clear conception might be had of how far the engineer has traveled on his way to his present accomplishments. I leave it to my hearers as to what these accomplishments have been. You are familiar with them. The alternating current, the steam-turbine, and the internal combustion engine have revolutionized our methods of travel and increased enormously the flexibility of the application of power.

Wireless telegraphy and telephony have made it possible to record simultaneously any event at all points throughout the world and has increased the range of the human voice from a few feet to thousands of miles. The underlying principles of science have not been changed in securing these results. What has happened is that research has but unfolded further mysteries of these principles. There is yet much to follow. Engineering intelligence has been, and will be, necessary that the great problems for the benefit of humanity may continue to be solved. The engineer has not proceeded alone, and can not do so in the future. He, as is the case in other professions, must have his clients. Industry and government will call upon him for desired results, and must stake him while he applies himself to solve their problems.

The present business depression that has been with us during the current year is an evidence of unbalanced trade. Production has greatly outstripped demand. Argument is unnecessary to prove that the pressure of hard times will be relieved only as supply and demand become more evenly balanced. Undoubtedly one of the great influences that have promoted expansion of trade and business has been the work of the engineer. Perhaps these very accomplishments of the engineer to which we have so proudly directed your attention have been carried along at a rate beyond the ability of economic laws to govern them.

I might add that since the World War, especially in America, we have enjoyed an era of great public improvements. This has inured to the benefit of the engineer by giving him additional employment. The desire of the public for these improvements has been so insistent that little thought has been given to the question of the necessity for them. Sooner or later the taxes following such an unscientific procedure will become a burdensome part of the cost of living.

Out of the expansion of facilities and methods for doing business, and the increase in public improvements, has come the advancement in the profession of the engineer. The present depression is the reaction from what he has done. When he realizes his connection with what is now happening he should set himself to the task of minimizing these future unfavorable reactions by applying scientific principles to his planning.

The next 50 years should be more wonderful than the last. Science will enjoy greater triumphs, which will add to the importance of the engineering profession. This Society will grow and its importance to this community will be vastly greater. It is within the range of probability and possibility that some of you here to-night will answer to the roll-call of the centennial. We suggest that you carry to that anniversary a reflection of the great pride we, at this Golden Jubilee, feel in our Society.

Had time permitted, I would have liked to mention by name many of my old friends who were members of this Society in the first 25 years of its existence. There were others besides those mentioned in this address.

HISTORY OF CIVIL ENGINEERING IN WESTERN PENNSYLVANIA*

By Morris Knowles†

INTRODUCTION

On this occasion, the fiftieth anniversary of the incorporation of the Engineers' Society of Western Pennsylvania, it is appropriate to review the local engineering events of that half century, and to pay tribute to the pioneers of the Society for their leadership in community affairs of an engineering nature. It is profitable to note the change in engineering methods from the era of trial and error to the attack by thorough study and investigation, and the intensive planning of individual projects to fit the whole.

While civil engineering originally comprehended all engineering not of a military character, this monograph confines itself to those activities having to do with waterways, transportation facilities, public works and sanitation.

WATERWAYS

The early history of Pittsburgh is inextricably linked with the history of the rivers and their development as improved waterways. The heritage of our close relation and our debt to our rivers has come down to us so vividly that at the Sesqui-centennial Exposition in Philadelphia in 1926, Pittsburgh placed itself on record with words paraphrased from the historian, George Bancroft (from his 1859 history of the United States), in a slogan first ascribed to William Pitt:

> "For as long as the Monongahela and Allegheny shall flow to form the Ohio, as long as the English tongue shall be the language of freedom in the boundless valleys which these waters traverse, Pittsburgh shall stand as the gateway of the West."

If a single *raison d'être* could be ascribed to Pittsburgh's beginning, it would be her favorable location with respect to inland water transportation. Before good roads checkered our country and railroad lines hooped its scattered outposts together, the waterways system was the one life-giving artery that new settlements required to insure stability, growth and success.

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The land at the junction of the Allegheny and Monongahela rivers was the object of English conquest in frontier times because of its commanding position with regard to the whole West. George Washington, the country's first engineer, as well as its first President, was possibly the first to pen an expression of confidence in and vision of a great potential future as an artery of travel and transportation for the Ohio River. In reporting on one of his early journeys, he said:

"Prompted by these actual observations, I could not help taking a more extensive view of the vast inland navigation possibilities of the United States, both from maps and the observations of others as well as myself, and could not but be struck with the immense extent and importance of it and with the goodness of that Providence which has dealt its forces to us in so profuse a hand. Would to God that we may have the wisdom and courage to improve them."

The President of the United States to-day—also an engineer—speaking on the occasion of the celebration of the ostensible completion of the Ohio River waterway project, said:

"While I am proud to be the President who witnesses the apparent completion of its improvement, I have the belief that some day new inventions and new pressures of population will require its further development. In some generation to come they will perhaps look back at our triumph in building a channel nine feet in depth in the same way that we look at the triumph of our forefathers when, having cleared the snags and bars, they announced that a boat drawing two feet of water could pass safely from Pittsburgh to New Orleans. Yet for their times and means, they, too, accomplished a great task. It is the river that is permanent; it is one of God's gifts to man, and with each succeeding generation it will grow in the history and tradition of our nation."*

So it is natural to find in a history of Pittsburgh that:

"One of the earliest industries of which there is any record is that of boat building. After the completion of Fort Pitt, the Government, in the Spring of 1760, dispatched seventeen boat builders to this point to build bateaux for use on the Ohio and its tributaries."†

John McKinney, a prisoner in Fort Duquesne in 1756, said that, during his imprisonment, about thirty bateaux and about 150 men

*President Herbert Hoover, in address at Louisville, Ky., Oct. 23, 1929, as reported in *United States Daily*, Oct. 24, 1929.

†History of Pittsburgh, by Sarah H. Killikelly. 1906. Montgomery, Pittsburgh. (See p. 88.)

came up the Ohio from the Mississippi "loadened" with pork, flour, brandy, peas, and Indian corn.

The rivers were the great highways of travel. The Monongahela was declared open to the public in 1782 and the Ohio and Allegheny soon after. The facility of transportation, together with the town's importance as a trading post and point of transhipment from a land route to a water route remained the chief elements in its growth down to 1800.

In 1811, the steamboat "New Orleans" was built in Pittsburgh—the first steamer to run in western waters. It cost $38,000 and was 138 feet long and 20 feet in beam. In September of that year, after short experimental trips, she commenced her voyage to New Orleans, freighted with the fears and doubts of the generally skeptical public concerning the outcome of what was then considered a hazardous and foolish venture. A successful conclusion of the voyage dispelled the anxieties, won confidence for steam-propelled vessels, and gave an impetus to the movement for developing the rivers into more usable channels of trade.

The beginning of the movement to slackwater the Pittsburgh rivers followed this historic trip; the state Act of March 24, 1817, incorporated a company for lock navigation on the Monongahela River. Various other movements, attended by greater or less success, were inaugurated in the succeeding years, and finally, in the organization of the Monongahela Navigation Company under the Act of March 31, 1836, the most important advance was made. Locks were built, and tolls were first collected in 1841. The original capital stock of this company was $300,000, later increased in order to complete the control works. How well this company built may be judged by the fact that on July 7, 1896, the Government purchased the seven dams and eleven locks in this system for $3,761,643.

Ohio River. The Ohio River is 980 miles long from Pittsburgh to Cairo, Ill. From Colonial days until the building of railroads it was the most important route of travel into the West and the Mississippi Valley. Cities grew up along its banks—Wheeling, Parkersburg, Huntington, Cincinnati, Louisville, and Evansville. Its usefulness, however, was seasonal in character, obstructed as it was at low stages by numerous bars over which there was shallow water only,

and by the falls at Louisville, the passage of which by the steamer "New Orleans" was the most hazardous moment of that epochal voyage. Until 1879 the work of the federal government on the river was confined chiefly to the removal of snags and the construction of contracting dikes at critical points.

In 1879 Congress authorized the construction of a lock and dam five miles below Pittsburgh—the old Davis Island dam. This was the beginning of the canalization of the Ohio River, although the formulation of a plan for the whole river did not materialize until 1910. Not every one was in favor of the first dam at Davis Island. Fixed dams especially were then, as later, the bane of certain navigators who feared the delay incident to maneuvering through the locks. As a compromise, the first dam was built of the movable type, with wickets capable of being lowered to permit free navigation when river stages permitted.

In 1910 Congress adopted a project for the entire river which was intended to provide for a navigable depth of nine feet throughout, by the construction of a series of low-lift, movable dams. Here was the basic plan, the fundamental framework, for the waterway of which we have recently celebrated the completion. Here were vision and foresight of which we have just witnessed the blossoming and full fruition. The benefits of adequate planning could hardly be better pictured, or visioned.

Possibly the plan had its inception in 1879 when the first dam was built, and the project of 1910 was a final revision of the scheme, embodying improvements in the details and a restatement of objects. Whichever way, certain it is that the development of the Ohio has been along the lines of a comprehensive program, with each individual step a contribution towards the completion of the whole project. Changes were made, and delays encountered, but in retrospect these disappear in comparison with the splendor of conception and accomplishment in the ultimate plan for improvement of the waterway.

It is interesting to note that the structures going to make up the whole scheme were built in the order of their usefulness. First, those in the upper reach where the slope was greatest and where they served as an extension of the canalized Monongahela River; second, at points below the larger cities where they served to create local

harbors and encouraged the construction of terminals by private capital; and third, by the construction of alternate dams in certain reaches, which made it possible to develop, by means of artificial freshets, low-water traffic in those reaches while the remaining dams were being built.

At one time the Ohio was looked on chiefly for its value as a connecting link between the East and the Mississippi territory. Developments changed this to focus the light of importance on its local traffic, which is the explanation for the order of procedure in the construction of the project. The earlier view of the river would have called logically for development from Cairo east or from Pittsburgh west.

Lake Erie and Ohio River Canal. Pittsburgh has another waterway project upon which much engineering work has been done—the proposed canal connecting the Ohio River and Lake Erie. As long ago as 1887 the Pennsylvania Legislature appropriated $10,000 for investigation of the feasibility of such a canal. This was but a preliminary step and since then the Chamber of Commerce of Pittsburgh, a private ship canal company,* and later a canal board of the state (the Lake Erie and Ohio River Canal Board of Pennsylvania),† have sponsored surveys and investigations of the route. It is estimated that the canal will cost approximately one hundred million dollars. The preliminary surveys and investigations which are demanded for a work of this magnitude, and which have been made largely under the supervision of members of this Society, constitute a notable engineering contribution to the store of useful knowledge regarding the potentialities of this district of Western Pennsylvania.

FLOOD CONTROL AND RIVER TERMINALS

Any extensive consideration of the history of the development of our rivers brings us quite naturally to the history of their regulation. We have improved them for purposes of navigation. Boats of deeper draft may traverse them at all stages of the year. Their benefits are being converted from seasonal to constant use. It has been

*Lake Erie and Ohio River Ship Canal Association.
†*Greater Pittsburgh,* v. 8, Sept. 25, 1926, p. 1.

suggested by President Hoover that new improvements will be made, that the completion of our work on the rivers is apparent only and not real. It can not be real, even to the present degree of improvement, until more adequate means of taking advantage of the improved facility of movement are developed. The thoughts of the people have been so focused upon the improvement of the rivers that the improvement of their corollaries, the river banks, has been in lethargy. The history of river terminal development in Pittsburgh has been a dark page until recent months. Forward-looking industry years ago planned to meet the canalization of the river upon a platform of loading facilities worthy of the benefits that the new river brought. We have good examples of progressive thought and engineering accomplishment at isolated points along the streams. But the city of Pittsburgh has been dilatory. The subject was directed to the attention of the district in 1911 by the Flood Commission of Pittsburgh as a two-fold benefit combining wharfage facilities and protection from high water with a suitable flood wall and dock wall. An untaught electorate in 1912 voted against the expenditure of funds for such an improvement.

In the flood of March 1907 an area of 1600 acres was directly affected by overflow and a very considerable additional area affected indirectly by seepage. This area included real estate having an assessed valuation of $160,000,000. Numerous manufacturing plants had to stop operations. The heart of Pittsburgh's financial district was penetrated and many of the important office buildings in the business section were deprived of light and power. Thirty-four miles of streets, 17 miles of railroad tracks, and nine miles of street-car tracks were submerged. Finally, had the flood risen six inches higher, the main pumping station would have been put out of commission and the entire city left without water for domestic and fire protection purposes.

The Flood Commission of Pittsburgh was organized by the Chamber of Commerce, February 20, 1908, the year following the most devastating of the many floods that have harassed our city. Memory is a slate upon which tragedy writes with deleble hand, and time is a sure eraser. Recollection of the desperation of a city so lately in the throes of floods, its very existence menaced by high waters, dims in less menacing years and is difficult of realization.

Five years after the flood the people who through their leaders and city government and trade organizations had contributed money for a thorough investigation of flood remedies had so far forgotten their 1907 experience that they negatived the recommendations of the most complete study of flood control that had ever been made in this country. The explanation is not far to seek—the people were not ready. We have seen the same thing happen to other forward-looking projects. The unification of Pittsburgh and Allegheny was sought from 1854 and accomplished only in 1907. Our recent attempt to consolidate Allegheny County into the Pittsburgh Metropolitan District was defeated in its first local test. But the defeat of the bond issue for the flood wall in 1912 did not dim the luster of the work of the Flood Commission. It was and is a tremendously valuable piece of engineering study. Flood control and river regulation will come just as surely as the rivers flow and continue to remind us of the needs, and when they do come, the thorough study and investigation, the weighing and assaying, the testing and examination, those technical studies by Pittsburgh engineers which are so necessary a prelude to any major work, will for the most part have been done. This year we have evidences of renewed activity in consideration of river-rail terminals.

Scope of Flood Report. At the beginning of the Flood Commission's studies it was believed by the engineers that the subject was a purely local one, and they prepared to treat it as such. As the investigations developed, it became evident that the flood problem was not peculiar to Pittsburgh but that Pittsburgh's floods had a direct bearing on the flood troubles of other communities. Organized in 1908, its printed report is dated April 16, 1912.* In the intervening time, data were collected on rainfall and run-off in the Allegheny and Monongahela drainage basins; the literature of America and foreign countries was searched for valuable suggestions; surveys were made for reservoir sites on the drainage areas (covering an area of 19,000 square miles) of the two rivers uniting at Pittsburgh; studies were made of the flood records of these rivers and of the flood damage in the Ohio Valley and Pittsburgh in March 1907, and for other similar disasters; and at all times flood control was considered in its

*Report of Flood Commission of Pittsburgh, Penna. 2 v. 1912. Pittsburgh.

relation to water-power, water-supply, sanitation, navigation, and terminals. It was in the broad sense an investigation of river regulation.

Recommendations. In conclusion, the report recommended the construction of 17 storage reservoirs on the headwaters of the two rivers, together with the erection of a low river-wall from the Smithfield Street bridge on the Monongahela to the Ninth Street bridge on the Allegheny, the wall to have modern dock appliances and loading facilities in connection therewith. These means of flood prevention and protection are calculated to reduce future flood heights to below the danger mark. They will assist navigation, increase water-supply for several purposes, and improve the sanitary condition of the rivers.

As a direct result of the Flood Commission's activities, many streets in the down-town section and in the lower North Side were raised above ordinary flood level. Except that power companies have in one or two instances built dams at or near the sites recommended by the Flood Commission, the storage reservoirs have not been built, nor the flood wall; but the latter, combined with terminal facilities, is pressing for reconsideration at the present time.

The cost of the works recommended by the Flood Commission was estimated at that time to be $20,000,000. Investigations by the Commission of the damage from three floods occurring within a period of one year and five days showed a loss of about $6,500,000.

By authority of Congress, the plans of the Flood Commission were investigated by the National Waterways Commission, which gave complete approval of them and recommended that Congress take steps towards the construction of the storage reservoirs. Subsequent review by the United States Engineer office is not so favorable.

RAIL TRANSPORTATION

While Pittsburgh has stood alone at the head of the procession in the development of transportation by waterways, it has enjoyed comparably with other cities the development of railroads in the country. In 1794, transportation of goods from Philadelphia and Baltimore to Pittsburgh cost $200 to $220 a ton. In 1834, the Commonwealth of Pennsylvania opened its canal—a rail and water system from Philadelphia to Pittsburgh—and reduced the cost of freight to figures between $14 and $22 a ton. This old tow-path was the

antecedent of the present railroads. The route was by rail, from Philadelphia to Columbia, 82 miles; by canal, from Columbia to Hollidaysburg, 172 miles; by portage railroad over the mountains, from Hollidaysburg to Johnstown, 37 miles; and by canal, from Johnstown to Pittsburgh, 104 miles. This system cost, to build, $12,000,000.

In 1846 the Pennsylvania Railroad was chartered to build a line from Harrisburg to Pittsburgh, and this line was completed in 1854.

The Ohio and Pennsylvania Railroad, later the Pittsburgh, Fort Wayne and Chicago, reached Pittsburgh in 1852, established its station at Federal Street, Allegheny, and continued its headquarters at Pittsburgh, officered by Pittsburghers, and with an engineering staff composed largely of members of this Society.

In 1857 the Pennsylvania Railroad purchased the Pennsylvania canal and thus enabled the Ohio and Pennsylvania Railroad to cross the canal, reach the Allegheny River, cross this, and enter the Pennsylvania station in Grant Street. This did not mean a through line across Pittsburgh, however, for the state governments believed in the policy of preventing operation of through trains from east to west or vice versa, and in carrying out this policy Ohio fixed the gage of her railroads at 4 feet 10 inches, while Pennsylvania made hers 4 feet 8½ inches. Thus there was no interchange of rolling-stock between these two railroads. It was not until a number of years later that the cars of the Pennsylvania Railroad Company passed west of Pittsburgh.

Early Conflicts. With the extension of the railroads across the rivers they came into physical conflict with the river interests, which claimed inadequate clearance beneath bridges and inadequate space between bridge piers for the free movement of cargoes. Navigators protested against the interference with their rights of way and railroads responded defiantly, claiming government subsidy of waterways to be an unfair handicap and disparaging transportation by water as uneconomic without government aid. Thus the political and controversial aspects of the situation dimmed the real achievements of the last half of the nineteenth century in railroading, and obscured the engineering accomplishments which conquered mountain and stream to link the East with the West in great systems of transportation.

Possibly, however, we may attribute to the soundness of the engineering principles upon which both water and rail transportation systems are built, their combined survival through this political turmoil, and the increased mutual tolerance that exists to-day. We may look forward to connecting these two agencies more closely through the medium of river-rail terminals.

The original plans for the Baltimore & Ohio Railroad called for the establishment at Pittsburgh of one of its western terminals. In furtherance of this project, the Pittsburgh and Connellsville Railroad was chartered in 1837, but it was not until many years later that connections between the Pittsburgh and Connellsville Railroad and the Baltimore & Ohio Railroad were made. Political and engineering difficulties stood in the way until 1871. Benjamin H. Latrobe was chief engineer of the Baltimore & Ohio Railroad when this historic connection was made. There had been sharp conflicts between the Pennsylvania Railroad and the Baltimore & Ohio Railroad for the right to enter Pittsburgh, which was considered then, as to-day, the very center of the traffic pie.

Not only in the construction of railroads, but in their operation, members of this Society have had their part. A notable contribution to the maintenance of operation on the Baltimore & Ohio Railroad was the temporary bridge over the Muskingum River at Zanesville, Ohio, built to replace the regular bridge which had been carried away in the flood of March 1913. This was the work of the late Paul Didier, a member of this Society.

The Pittsburgh & Lake Erie Railroad, which has been known as the "Little Giant" because of its high earnings per mile of track, was the last of the railroads to enter Pittsburgh. This line was chartered on May 18, 1875, and the projected route was from the depot grounds of the Pittsburgh and Connellsville Railroad in the second ward of Pittsburgh; thence across the Monongahela Railroad to the thirtieth ward; and thence substantially as now to the Ohio state line. Contracts were let in 1877 for the construction of the road from the Jones & Laughlin plant on the South Side, in Pittsburgh, to Haselton Furnace, Ohio. Regular passenger and freight service was inaugurated on the railroad on February 24, 1879, after some difficulties in construction (chiefly in the matter of serious slides along the right of way and bridging the Ohio River at Monaca)

had been overcome. The Harmony Society of Economites was prominently identified with the early years of the road. Jacob Henrici became a director in 1878 and president in 1881, which position he held for three years. Even before operation of the railroad, contracts favorable to the handling of freight were made with the Lake Shore and Michigan Southern Railroad, of which W. H. Vanderbilt was president. Through these contracts, Vanderbilt subscribed to stock in the Pittsburgh & Lake Erie Railroad and later became one of five trustees. Several of the Vanderbilt family have served on the Board of Directors. In April 1877 the Youngstown and Pittsburgh Road was chartered and in 1878, by consolidation, became a part of the Pittsburgh & Lake Erie. This completed the route from Pittsburgh to Youngstown. In 1883 the Pittsburgh, McKeesport & Youghiogheny Road was opened and the following year was leased by the Pittsburgh & Lake Erie Railroad, giving the latter road access to Connellsville. The McKeesport and Bellevernon Railroad was bought by the Pittsburgh & Lake Erie Railroad in 1889.

Railroads came to Pittsburgh in the rôle of long-distance carriers to shorten the time and lessen the cost of transportation and travel between East and West. They played their part well, but they have added to their repertoire the not less important part of contributing to the relief of the intercommunity rapid-transit problem. The Pittsburgh that began as a blockhouse in 1754 soon flung itself back along the rivers and out over the hills in industrial and other activity. The intramural transport of the city became as perplexing a matter as the intercity problem of an earlier generation. To the solution of this the railroads have contributed in no small measure. In October 1921, of 593 trains entering and leaving the city daily, 327 were suburban and had their origin or destination at from 16 to 45 miles from Pittsburgh.

Street-Cars. Starting in 1859, horse-cars had been introduced here in an attempt to solve local transportation problems. These served until 1887, when one of the first electric lines in the country was installed from the intersection of Carson Street and Thirteenth Street on the South Side up the steep grades to Knoxville borough. At this time there was considerable doubt in the minds of railway engineers as to the relative advantages of cable and of electric trac-

tion for street-car purposes, and the experiment in Pittsburgh was a decided contribution to the art. The first cable line, extending from Fifth Avenue and Liberty Street to Shady Avenue, was opened for business September 12, 1889. Gradually the electric system demonstrated its superiority over cable lines.

In the early 'eighties there was some doubt of the character of service that the burgeoning electric street railway was going to be able to render. Upon its ability to make the suburbs of Pittsburgh accessible hinged the selection of the new site for the Western University of Pennsylvania on Observatory Hill. The final selection of the site placed the stamp of approval on the electric railway. Twenty years later the street-car company was believed to have reached the *ne plus ultra* of accomplishment—at least on the surface of the ground. A historian, in 1906, wrote:

> "In facilities for local traffic by electric railways, Pittsburgh has reached the limit in so far as surface lines are concerned. Owing to the physical limitations, there is but little room to provide for the increasing traffic. Routes must be established, either above or below the surface, and the day is not far distant when actual operations must begin on them."*

This is the fate of a historian who casts aside the pen of past events for one of prophecy. Save for a one-mile bore through the cliff on the south banks of the Monongahela, we know of the raising of no pick or the drilling of no hammer that would bring this prophecy of 25 years ago one step nearer the saving grace of fulfilment than it was before the ink with which it was written was dry.

Yet this writer was not alone in her predictions. In 1903 the Engineers' Society of Western Pennsylvania listened to a paper† advocating an elevated loop rather than a subway for the relief of street congestion. In no field of our activities does thought appear to have led achievement so far as in the solution of the problem of rapid transit and traffic congestion.

In 1907 another paper‡ was read before this Society describing a proposed subway which had been carefully worked out by one of the companies then seeking a charter for construction. At this time the advocacy of the elevated loop had been superseded by the underground plan. There was to be a loop down town, a branch across the

*History of Pittsburgh, by Sarah H. Killikelly. 1906. Montgomery, Pittsburgh. (See p. 240.)

†Proceedings, 1903, v. 19, p. 602.

‡Proceedings, 1907, v. 23, p. 49.

Allegheny River to the North Side and a line to East Liberty, also with branches.

Two years later, in 1909, interest in the subject had assumed such proportions that a meeting to discuss "Rapid Transit for Pittsburgh" was held by the Chamber of Commerce. There had been requests for charters from several companies wishing to build and operate the line. Routes, loops, terminal locations, and other details were discussed. Laymen at the meeting were enthusiastic. There was talk of four-track subways to accommodate both express and local trains.

Rapid Transit. In October 1916, City Council authorized the appointment of a Transit Commissioner to investigate the subject and report on a means of obtaining rapid, efficient and cheap transit throughout the city and its suburbs. Previous to the appointment of the Transit Commissioner there had been several investigations and reports, but most of them dealt with current conditions and their possible amelioration by rerouting of surface cars. The Transit Commissioner, a past president of this Society, thus became the first to give to this question the thorough and comprehensive study that a problem of its magnitude requires. His report* forms a preliminary plan from which we may hope for gradual improvement of conditions, keeping step with the growth of the city. A later report by the Citizens Committee on City Plan of Pittsburgh† was in agreement for the most part with that of the Transit Commissioner.

In the minds of many, rapid transit immediately conjures up fast subway trains, and, knowing that Pittsburgh has no subway, they think that Pittsburgh has no rapid transit; but rapid transit means many more things than subways. As a matter of fact, in two pages of recommendations prefacing the report of studies of the Transit Commissioner the word "subway" is not mentioned. Rapid transit means other engineering studies and accomplishments—streets to be widened, new arteries and boulevards provided, effective parking regulations enforced, street-cars rerouted, and finally, rapid-transit lines. Many of the recommendations of this report have been carried out. The work has gone on under the City Traffic Commission,

*Report of Transit Commissioner to the Honorable Mayor and the City Council of the City of Pittsburgh. 1917. Pittsburgh.

†Transit; a Part of the Pittsburgh Plan. 1923. Citizens Committee on City Plan of Pittsburgh, Pittsburgh. (Report No. 3)

later the Transit Commission, under the chairmanship of George S. Davison, a past president of this Society. In 1925 a report* was made on a recommended subway for the first and second wards of the city, and in the following year a plan† was drawn up for financing this subway. Both of these reports were made possible by a vote of the people, in 1919, to increase the city's indebtedness by $6,000,000 for subway purposes.

AIR TRANSPORTATION

The newest form of transportation to call upon the resourcefulness of the civil engineer is aviation. Pittsburgh has responded by careful study of the selection of an airport site, recommended by a committee of the Chamber of Commerce upon which were members of this Society, and, with the selection made, is at present engaged in developing an airport on the Lebanon Church Road, where a site of 400 acres is available for this purpose. Work has already begun on the necessary grading and drainage of the field.

BRIDGE ENGINEERING

An engineering contribution of no small degree of importance to the rapid-transit situation in Pittsburgh has been made by the many and beautiful bridges built in the district. While our location on the rivers has brought us many benefits, it has brought us also the necessity of bridging these streams to prevent isolation and to unify the Pittsburgh region. The uneven topography has made additional bridges necessary over some of our deep ravines. Altogether we have more than 500 railroad and highway bridges in Allegheny County.

From an attempt merely to cross the rivers in the easiest way possible, we have progressed to crossings that have due regard to the free passage of river craft beneath the bridges, and to crossings that combine beauty with utility.

The first bridge in the district was one across the Monongahela, opened in 1818, consisting of wooden arches on stone piers, its flooring suspended by means of iron rods. It cost $102,000. We have lately completed over this same river the beautiful and enduring

*Report on a Recommended Subway in the First and Second Wards of Pittsburgh. 1925. Traffic Commission, Pittsburgh.

†Communication from the City Transit Commission of Pittsburgh to the Mayor and City Council, Containing a Report on a Plan for Financing Initial Subway Construction in Pittsburgh. 1926. Pittsburgh

Liberty bridge at a cost of $3,771,000. From 1818 to date Pittsburgh has at times led and always kept pace with the developments in the bridge-building art. The first wire cable suspension bridge built anywhere was that which carried the aqueduct of the Pennsylvania state canal across the Allegheny River. It was designed and built by John A. Roebling in 1844. The next year he built a second bridge at Smithfield Street to cross the Monongahela, replacing the original covered bridge which burned that year.

The Larimer Avenue bridge, built in 1912, set a record in America for length of concrete span (312 feet). The Beechwood Boulevard concrete arch bridge won for John D. Stevenson, a member of the Society, the second prize in the 1929 Phebe Hobson Fowler award of the American Society of Civil Engineers, in which the Hell Gate bridge in New York won first prize.

Early in the present century the bridges on the Allegheny became the subject of attack as unreasonable obstructions to navigation. The United States Army engineers consistently favored petitions to compel alterations to the bridges, giving greater clear height beneath their floors, until 1917, when Secretary of War Newton D. Baker declared "Their immediate elevation and the relocation of their piers is necessary in the national interest." The Pennsylvania Railroad Company began at once the raising of its bridge at Eleventh Street and proceeded to lift this huge structure 13 feet vertically to comply with the War Department order. The work was accomplished in five months of operation and without interference or interruption of traffic over the bridge—a noteworthy engineering feat. For Allegheny County the order meant new bridges at six locations—Sixth, Seventh, Ninth, Sixteenth, Thirtieth, and Fortieth streets. The magnitude of the construction program, including many trunk highways as well as bridges, facing the county, resulted in the formation in 1924 of the county Department of Public Works, headed by a capable engineer, a member of this Society, to whom, for the successful carrying out of the bridge-raising program and excellent work in other major projects in the county, great credit is due. The Sixth, Seventh, and Ninth street bridges are of the same type of design—self-anchoring suspension bridges. The Sixth Street bridge won the award of the American Institute of Steel Construction for the most beautiful steel bridge built in 1928 in the United States.

HIGHWAY ENGINEERING

A rapid growth has taken place in the highway engineering branch of the profession due to the advent of the motor-driven vehicle. To keep abreast of the demands made by the general public for improved highways has required ingenuity and resourcefulness on the part of the engineers of western Pennsylvania who have dedicated themselves to this work.

The first road westward across the mountains was laid out in 1743 by the Ohio Company—a party of Virginia gentlemen who had been granted 200,000 acres on the Ohio River, between the Monongahela and the Kanawha rivers—and this road was probably nothing more than a blazed trail. It was over this road that Washington traveled in 1753, at the behest of the Governor of Virginia, to inquire of the French their rights to build forts on the Allegheny River. Again in 1754, when war with the French seemed inevitable, he made the same trip over the same road, this time taking with him 300 men and 10 swivel guns. In the year 1755, it was over this same road that Braddock advanced from Fort Cumberland with 2200 soldiers and 600 pioneers. This, in part the National Highway, the first road across the mountains, was the only one until 1758, when General John Forbes, sent against Fort Duquesne to redeem the failure of Braddock, built or rather opened a new one by way of Bedford and Ligonier. These two roads remained as the only routes of white-man travel across the mountains until 1775, when the Transylvania Company was organized and Daniel Boone was sent to mark out the Wilderness Road through the Cumberland Gap to Kentucky.

The next step in the development of roads was the creation of the turnpike, whereby tolls were collected for construction and maintenance. The first turnpike to be built by private capital was the famous Lancaster Turnpike, which was built by the Philadelphia and Lancaster Turnpike Company, incorporated by the state legislature on April 9, 1792. The old Steubenville Pike was one of the original toll highways located in western Pennsylvania.

In 1894 a progressive step was taken when the people of Allegheny County, under the authority of a legislative act, granted power to the county commissioners to assess taxes for the purpose of building and maintaining county roads. This was the first county in Pennsyl-

vania to have such a program, and it preceded the state's adopted policy by many years.

With the emergence from primitive highway conditions there was no radical change from the original highway plan. Highways in Allegheny County formed a system of spokes with Pittsburgh as a hub and cross-country or belt-connecting roads were scarcely considered.

In 1894 there began an era of business development and, with the advent of the motor vehicle, through traffic originated and intercounty traffic developed. These changes necessitated a broader plan of development, which brought about a public works reorganization and financing plan undertaken in 1924. With the creation of the new Department of Public Works, the county commissioners submitted to the people on April 22, 1924, a $29,000,000 bond issue for roads, bridges, and tunnel.

The Liberty twin tunnels at the time of their completion in 1924 were the first long artificially ventilated tubes ever built in this country or abroad for the accommodation of automobile traffic.

The Bigelow Boulevard conceived by the Director of Public Works, a member of this Society, was an early achievement in the construction of main boulevards as an aid to facile movement of traffic. The Boulevard of the Allies, a more recent product, and still later the Mt. Washington Boulevard, evidence the highway engineers' participation in the development of Western Pennsylvania.

The latest step in the development of our highway system was taken when the bond issue of June 26, 1928, was passed by the electorate. This issue provided for the construction of the Saw Mill Run Boulevard, the Allegheny River Boulevard, the Ohio River Boulevard, and the Moss Side Boulevard, at a total cost of approximately $10,930,000.

The voice of the people spoke and the engineers are now providing them with the boulevards desired. This bond issue also provided $6,550,000 for the construction of new highways, reconstruction and widening, joint improvements, elimination of grade crossings and dangerous curves, and the erection of safety barriers.

SANITARY ENGINEERING

By improving the facilities for navigation on the rivers, engineers gave to Pittsburgh the benefits of low-cost transportation and increased the city's commercial importance. Highways, railways, and rapid transit similarly bring benefits in comfort, convenience, and business prestige.

There is, however, another branch of engineering where the direction of the forces of nature affects us in a much more intimate way. It makes urban life possible and comfortable. I refer to the engineer who provides us with a safe and adequate water-supply and means of disposal of wastes. It is not necessary here to dilate upon the importance of this in the life of the city. To-day we are accustomed to take our water-supply for granted. Yet Pittsburgh's history in this respect stands out among that of similar cities the country over as the story of the conquest of disease and death.

Water has ever been available here in quantity since the time when there were pumps to lift and pipes to carry it. As far as the adequacy of a water-supply is concerned, Pittsburgh's location on great rivers has again conferred a benefit on its citizens. Regarding the quality of the supply, there is another story. Use of the Allegheny and Monongahela rivers for water-supply without treatment was the vogue for years until sanitarians pointed out the danger and the remedy.

The danger was an imposing specter, not difficult to seek out. The deaths from typhoid fever in Pittsburgh from 1880 to 1890 ranged from 130 to 315 a year in a population that averaged 200,000 for the decade. The figures were higher than in other cities, even in some using more highly polluted sources of water-supply.

Lawrence Experiments. In 1889, in a little wood frame house on the banks of the Merrimac River in Lawrence, Mass., there began a series of experiments on the filtration of water and sewage through sand—experiments which were destined to a permanent niche in history's Hall of Fame for the far-reaching benefits that their results brought to cities all over this country and Europe. Here, under the genesis of Hiram F. Mills, C. E., then a member of the Massachusetts State Board of Health and later honorary member of the American Society of Civil Engineers, the biological laws governing the actions within a sand filter were first discovered.

In 1893, the city of Lawrence, using the Merrimac River water, put in operation a slow sand filter for the purification of the supply. It was the first practical application of the new knowledge that had come out of the now historic experiment station. It was the first sand filter designed in the full knowledge and comprehension of its biological possibilities and for the definite purpose of saving human lives. The results were astounding. Cases of deaths from typhoid fever, which had flourished in the city using a water-supply taken from the river nine miles below the point where the sewage of the city of Lowell fouled the stream, were remarkably and suddenly reduced.

Sanitary engineering was born in that little frame house beside the Merrimac River. News of the important work done there spread rapidly among engineers and physicians. One of the former here in Pittsburgh, James H. Harlow, personal befriender of the writer, Past President of this Society, a New Englander by birth, brought the import of it to Pittsburgh through the medium of a paper* read before this Society in 1893. He pointed out the terrible toll that dysentery and typhoid had exacted of Pittsburgh and Allegheny. He told the story of Lawrence and the Merrimac River, and he pointed the moral so strongly that his hearers were moved to action forthwith. The Society appointed a committee to represent it on a Joint Commission which had been announced almost simultaneously and which had representatives (besides those of the Engineers' Society of Western Pennsylvania) from the Chamber of Commerce, the Allegheny County Medical Society, and the Iron City Microscopical Society. The Joint Commission worked from the spring of 1893 until the fall of that year. It made a report, published in 1894, in which it unequivocally recommended the earliest possible construction of a filter plant. The report was strongly phrased, reflecting the firm conviction of authors straining to sway an inert populace to action. The then current water-supply of Pittsburgh and Allegheny was described as "pernicious." The deaths from typhoid fever were found to show a larger percentage of the population than any other city in the United States. The work of the Joint Commission is fully described in a memorable paper,† entitled "Story of the Efforts Which Led to the Purification of the Water-Supply of Pittsburgh, and to

*PROCEEDINGS, 1893, v. 9, p. 109.

†PROCEEDINGS, 1927, v. 43, p. 179.

the Elimination of Typhoid Fever from That Cause," presented in 1927 by James Otis Handy, a past president of the Society.

Filtration Commission. On June 8, 1896, the quest for pure water and the attempt thereby to eliminate water-borne diseases took an official character when the Mayor appointed the Pittsburgh Filtration Commission, and directed this Commission "to investigate the effect of sand filtration and the advisability of establishing a sand filtration plant for the city of Pittsburgh and maintaining the same." The Commission, an able body of men, headed by Robert Pitcairn as Chairman, turned quite naturally, as the first step in what they correctly construed to be their important task, to that cradle of sanitary engineering located at Lawrence, Mass. In a body the Commission visited the filtration beds there on November 11, 1896. The mission was one of search for information, but it was doubly fecund, for the Commission found there not only a demonstration of a practically applied filtration plant, but also the personnel which they required to carry out the technical assignment that was theirs. It was natural that from the East should come the men practiced in the new art, since in the East the new art began and at that time was farthest advanced.

From Lawrence, then, came the late Allen Hazen to become consulting engineer of the Commission, William Rogers Copeland to be its bacteriologist, and the writer to be its resident engineer.

It is to the credit of Pittsburgh that its Filtration Commission had civic courage and went so unhesitatingly and so early to the East for men and ideas. With all deference to the splendid men who were in Pittsburgh at that time, the fact remains there was none who called himself a sanitary engineer. The particular branch of this Society that had busied itself with the water-supply problem of Pittsburgh and Allegheny up to that time had been the Chemical Section. Chemical examinations and analyses of water, rather than bacterial tests, were then the sole measures of its quality, and consequently the chemical engineers of the Society were in the direct line of descent to inherit the dubious honor of testing what then passed for water-supply.

The scope of the work of the Filtration Commission was most comprehensive, for, although the specific nature of its title would

belie it, the Commission was charged with a complete investigation of Pittsburgh's water-supply. This included the question of bringing in another source to replace the Allegheny River. Thus the Commission's task was the formulation of a comprehensive plan for Pittsburgh's future water-supply. There is no record in the city's history of any previous study or plan upon which the waterworks system as then constituted was predicated. Like Topsy, it just grew. When wells on Market Street became inadequate for the rapidly growing city, the alternative was naturally to take the abundantly flowing rivers. The Filtration Commission then, so far as the source of supply is concerned, was a tardy agency, reporting in retrospect. Yet upon the Commission devolved the privilege, and duty, of committing Pittsburgh to the Allegheny River forever for its water-supply, of committing it to modern methods of treatment, to the principle of utilization of the great natural resources with which the city has been so bountifully blessed. Thorough study was made of the possibility of introducing water from mountain streams that would have been purer in their natural condition than the Allegheny River, but the Commission resisted the temptation that this remote kind of a water-supply, usually deficient in quantity when the long-distant future is considered, holds for so many cities and so many individuals who have not learned that water can be purified. They staked the security and safety of the city on the ability of the then new sand filters to make of the muddy waters of the Allegheny a water-supply both hygienically safe and esthetically attractive.

The Commission also investigated the possibility of establishing a separate water system to serve mills and factories with water for other than drinking purposes. Its rejection of this was so final that the project never again attained any degree of importance, either in Pittsburgh or elsewhere.

The Commission made its report in 1899. Followed then the development of detailed plans, in accordance with its recommendations, the construction of the filter plant, the completion and placing in operation of the final units to give filtered water to all of peninsular Pittsburgh in 1908, and the extensions in 1910 to take care of the North Side (formerly Allegheny). With the completion of the filters, we have but to look at the record of the typhoid fever death rates in the years prior to and following the placing of the filters in

operation. A few simple figures tell the story. The death rate per 100,000 population dropped from 125 in 1907 to 49 in 1908, to 25 in 1909, to 13 in 1910, and never again went above 20. In 1929 the rate was 2.3 per 100,000, including deaths of non-residents in institutions, a rate lower than in most large cities.

No more eloquent tribute to the success of any engineering enterprise could be written. With the complete rout of water-borne disease from the city, with reliance placed on the always adequate supply in the river, the work of the Pittsburgh Filtration Commission, and later of the Filtration Bureau of the Department of Public Works, basically solved the fundamental features of the problem of Pittsburgh's water-supply for all time.

Looking back on the history of the development from a vantage point of forty years after, the scourge of typhoid and the possibility of its elimination were brought to the attention of the people largely through the efforts of the Engineers' Society of Western Pennsylvania.

The Filtration Commission was organized at a time when it had the example of but one predecessor to guide it—the famous experiment station and filter system at Lawrence. It was charged with the double duty of pioneering and planning. Possibly a criterion of the excellence of its work is the promptness with which its plans were carried to fulfilment. In their completion, how sound appears the work upon which the plan was based.

Other Water Systems. The water utilities of the Pittsburgh district employ methods other than that of slow sand filtration for purification. Many of the boroughs, and part of the city on the south side of the Monongahela River, get water from the South Pittsburgh Water Company, which utilizes a modern water-softening plant in its purification process. In the North boroughs, water is served by the Pittsburgh-Suburban Water Company, formerly the Ohio Valley Water Company, employing a still newer method of water softening (the "zeolite" process), and the installation made by this company on Neville Island was one of the first of its kind. The Pennsylvania Water Company in Wilkinsburg has a rapid sand filter plant; so that almost all the outstanding processes of water purification are represented in the Pittsburgh district—all planned and executed by Pittsburgh engineers, members of this Society.

Sewage Disposal. Upon another side of the sanitary branch of civil engineering, one closely allied with the subject of water-supply, the pages of history are less marked with the glowing badge of achievement. I refer to the treatment of sewage and trade wastes in the Pittsburgh district. Far from being able to tell you of a progress like that of our waterways, our railroads, our water-supply, our structures, the historian can tell you only that the subject is notable more for the lack of attention that has been paid to it than by reason of anything that has been done to further it. This is notwithstanding the fact that many of the sewer designs, including tunnels and long trunk lines, are unique, because of their difficulty in construction and expense. It is a sad commentary upon the state of the public mind that the subject of final disposal, so close to the health of the people, has been so perfunctorily passed over. It has been characterized by a public indifference that is nothing less than a civic shame.

It is no defense of our city's inactivity that municipal neighbors above and below us on the rivers have done no more than we have. It is a matter of common law that no city has the right to impair the quality of the water in the river as it flows past its riparian land. It has been a matter of statute law in Pennsylvania since 1905 that no city has the right to discharge untreated sewage into the streams of the state. The Purity of Waters Act of that year exempted existing sewer systems from the penalties of the Act, but the law intended to prevent the wide extension of existing systems to discharge into the streams without treatment.

It is not only in violation of the spirit and intent of the law; it is in violation of good sense, of esthetics, of public health, and of the right of people to use the rivers for recreational purposes. Pittsburghers should be glad not merely to meet minimum sanitary requirements but also to restore their streams and river banks to their once attractive condition. The fact that present trunks and outlet construction have been approved by state authority, that no new outlets have been added or extensions made to trunks existing in 1905, and that minor stream valleys have been relieved of gross unsanitary conditions, does not relieve the city from the moral and practical responsibility of doing more than it has done to better conditions.

If we turn from Pittsburgh momentarily, we find over the country a fresh ripple of activity disturbing the general stillness of

the pool of public apathy on this subject. Elsewhere, in isolated spots, at least, progress is being made. The eastern metropolis (Philadelphia) has prepared a comprehensive plan for the collection and treatment of sewage, and under an agreement between the city and the State Department of Health the city has obligated itself to spend $3,000,000 annually towards the works needed to put this plan into effect. The first units of one of three proposed treatment plants have been constructed and put in operation. The question is, will Pittsburgh lag in this as she has not done in any other field of endeavor? It is difficult to believe that she will much longer let this very urgent problem go untouched. There must be study and preparation; there must be diligent work and the formulation of a plan; there should be given to this subject the same kind of investigation and comprehensive planning that the Filtration Commission gave to the question of a water-supply, so that we can rest with the same sort of assurance in contemplation of our sewage disposal achievements as we do now in the matter of our water-supply.

Engineers have always been ready and willing to carry out the mandates of the people on such matters as these and the fact that there have been no steps taken toward sewage treatment in the Pittsburgh district is chargeable to the apathy of the public and not to the inability of engineers. Philadelphia exhibits a distinct mark of progress in carrying out a well considered plan, in contrast to the situation locally where the making of the plan still waits the awakening of the public.

Comprehensive co-operation between state and local authorities in a thoroughgoing plan to care for all wastes, and vigorous insistence upon the part of the state in meeting more than minimum sanitary requirements, are needed to prevent further spoliation and to attain some restoration of the original attractiveness of our water-courses.

COMPREHENSIVE PLANNING

The filtration system is typical of much that is done in engineering. On yonder bank of the Allegheny in Aspinwall, the visible and outward manifestation that anything more than a suspiciously large and smooth expanse of grass is there consists solely of two pumping stations and their stacks, an office building set apart, and one

or two small concrete arch bridges. The filters are covered. Doing their work day and night, they do it without benefit of watchful public approbation. In the austerity of their tombs, they represent remarkably well the spirit of engineering. Much is done that never sees the admiring gaze of crowds or hears the plaudits of an approving audience. Oftentimes a report of investigation represents more of the engineering in a project than what may follow in rearing a temple to the sky.

It is the history of engineering that through study and preparation alone can we arrive at the correct solution for the problem at hand. Given the solution in the form of a plan for development—a plan that reckons with the future as well as the present—we have made an engineering accomplishment of the first magnitude. We look with suspicion upon the durability of accomplishments that have not been preceded by thorough study and careful preparation.

Official recognition of the need for planning in municipal affairs led to a City Planning Commission, created by the city government in 1911. This Commission consists of nine members appointed by the Mayor and serving without pay. An engineering staff is employed whose technical studies and investigations form the basis of opinions rendered by the City Planning Commission on matters of civic development, which is one of its chief functions. The most noteworthy undertaking of the Commission has been the preparation of the zoning ordinance, which was passed by City Council July 31, 1923. This ordinance regulates the use of property and the height and bulk of buildings throughout the city and is an important part of a city plan.

The need for a City Planning Commission had been forcibly brought to light by the earlier activities of the Pittsburgh Civic Commission, appointed by Mayor George W. Guthrie, January 16, 1909, and having some engineer members. The Chairman was H. D. W. English, formerly president of the Chamber of Commerce. The purpose of the Commission, in its own words, was "to promote improvements in civic and industrial conditions which affect the health, convenience, education and general welfare of the people of the Pittsburgh industrial district; to create public opinion in favor of such improvements; and thus to establish such living and working conditions as may set a standard for the American industrial centers."

The Pittsburgh Civic Commission summoned to its aid in the study of the problems such men as Bion J. Arnold, noted traffic engineer; Frederick Law Olmsted, city planner; and John R. Freeman, hydraulic engineer. These three men together gave the Commission a report on a program for a city plan for Pittsburgh as long ago as 1910. Of the many works of a civic nature accomplished by or through the Pittsburgh Civic Commission, the impetus it gave to the formation of the official planning bodies in Pittsburgh is notable. Composed mainly of lay citizens, its early appreciation of the importance of engineering in civic works was significant.

In 1918 there was formed the County Planning Commission, cloaked with powers to recommend only, and its engineering staff has accomplished much for the fundamental improvements in the county.

As if to stress the importance of planning, which means thorough study and preparation for major improvements, we have also a Citizens Committee on City Plan—an entirely unofficial organization which, believing that Pittsburgh should have an orderly, scientific, and comprehensive program for its future development, has expended nearly a quarter of a million dollars in the study and preparation of a plan. This committee has studied and reported plans for playgrounds, street system, transit, parks, railroads and waterways. The inception of planning by the city, its perusal by the county, and its general encouragement by this unofficial group will logically lead to a regional planning movement, the desirable end to be attained.

ENGINEERING EDUCATION

Pittsburgh is yearly producing, in addition to engineering accomplishments, the technically trained men who will assure to this district a continuance of the production of engineering thought and accomplishments. In 1848, the first degrees in engineering were granted at the Western University of Pennsylvania, the earliest institution of higher learning west of the Allegheny Mountains. (The present name of the University of Pittsburgh was acquired in 1907.) Engineering education at the university is carried on under a co-operative plan through which the student supplements work in the class room and laboratory by practical work in the field with several engineering firms co-operating with the university. The university is at present constructing its "Cathedral of Learning"—a building unique

in type among campus structures, and one of the engineering and architectural monuments of Pittsburgh. The Carnegie Institute of Technology was founded in 1900 by a former member of this Society—Andrew Carnegie—and already has a large and notable group of alumni.

SUMMARY

The history of Pittsburgh's accomplishments in civil engineering is replete with careful plans and, where the plans have materialized in the works for which they have been intended, we rest secure in a confidence in those works. The history also reveals fields in which the plans have been made and are awaiting fulfilment. It reveals fields in which not even the plans are made. It is a story of work done and work in progress. It is a picture of a city with major accomplishments to its credit and major improvements ahead, with constant appreciation of engineering advice and opinion.

It reveals a percipient city, awake to the fact that its most successful accomplishments have been attained only after careful study, investigation, and planning, and preparing itself for the future by making plans now for the very much greater Pittsburgh of which the hundred-year history will be written for the Engineers' Society of Western Pennsylvania.

FIFTY YEARS OF MECHANICAL ENGINEERING*

By Julian Kennedy†

The past thirty years constituted a period of great development in all manufacturing, both in invention and in production. The developments in the blast-furnace and steel plant during this period have been of particular interest to those associated with the industry.

Previous to the year 1900, blast-furnaces were generally provided with a charging device consisting of a bell and hopper resting on a base ring, this base ring in turn lying on top of the brick lining of the furnace, and in some cases being fastened to metal brackets projecting inward from the outer plate shell of the stack and imbedded in the brick lining. Owing to various conditions, especially the use of a large proportion of soft, fine ores, there was often trouble with furnaces hanging and slipping. The stock would stop its regular descent and form an arch across the shaft at or above the bosh; the coke burning out below this arch would leave 2000 cubic feet or more of empty space in the lower part of the furnace. Finally this arch would give way and fall and the heated air in the open space below, often under a pressure of 15 pounds to the square inch, would rush up through the furnace with force enough to lift the bell and hopper and in some cases toss it clear off the top of the furnace, and also throw out a lot of coke and ore. To avoid blowing off the hopper, it was the usual practice to provide "explosion doors" arranged to open with a few ounces of pressure and allow a free exit for gases and stock. This to a certain extent prevented the blowing off of the top rigging, but allowed the discharge of hot stock, and it was not a very unusual occurrence to have fifty tons or more of hot coke and ore thrown out on the cast-house roof and sometimes scattered around the furnace for a hundred yards or so. These occurrences were called explosions and it was assumed that they were practically irresistible and that the only way to take care of them was to provide hinged safety-valves to give vent to them. The consequence was that large numbers of men were burned on top of the furnace and also on the ground and cast-house roofs and were then caught by another slip when cleaning up the previous one; also, great quantities of fine flue-

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†Engineer, Pittsburgh.

dust filled the air for miles around the furnace. In some cases sections of cast-house roof would fall in due to the excessive load of this material from the top of the furnace.

About 1895 the writer came to the conclusion that the ordinary slip was not accompanied by an explosion at all and that the gas pressure at the top of a furnace during a slip, when the furnace was reasonably full of stock, could never rise above the pressure of the blast and, therefore, if the top of the furnace were made strong enough to stand as much pressure as the hot-blast stoves, there would be no necessity of explosion doors and the hopper could be bolted solid to the furnace shell.

This theory did not appeal to many furnace operators, but finally the writer was able to equip a furnace, and in order that the test should be a thorough one no explosion doors were put on, the top of the shell was domed and the hopper bolted solid to it. Every manhole on downcomers, dust-catchers, and gas mains to stoves and boilers had a bolted cover, and even the bleeder at the top of the furnace was made to open inwardly. The downcomers were also constricted in area of opening close to the furnace to check, to a certain extent, the sudden rush of gases, and reduce the amount of solid material carried along by them. This furnace worked most satisfactorily and in its operation no man has ever been burned by a slip. The operator has always felt safe in going on top even if the furnace had been hanging and slipping. There being no opening or explosion doors on the furnace, all the flue-dust was forced down into the dust-catcher and cleaners, eliminating all flying flue-dust and making the plant and surrounding country a much cleaner place in which to live. This furnace had many slips, often dropping from 10 to 20 feet, and the pressure at the top never exceeded six pounds to the square inch. Even after this and many following demonstrations, it was several years before some operators were convinced that it was safe to close in a slip.

The average, old-time bell and hopper required about one pound per square inch to lift it, and a large volume of gas at a pressure of three pounds per square inch would toss the bell and hopper, together with the top rigging, clear of the furnace with so much force that it was assumed by many that if confined the pressure would at least reach 100 pounds per square inch. At the present time all furnaces are built strong enough to stand the pressure due to any slip.

Of course, there are at the present time explosions at furnaces. I recall a typical case when a furnace was being started, the blast had been on for an hour or two and one blowing-engine was running quite slowly. In charging the furnace a rather large amount of wood was put in the hearth and up the walls of the bosh. The gases coming off naturally had plenty of hydrogen in them. The gas had been lit in the stoves for some time and the boiler tender turned some into a boiler; presumably he opened his burner too much and failed to watch the pressure-gage on the gas main. Instead of maintaining a slight pressure, the main was under a slight suction. At this point the stove man, for some unknown reason, opened the dust-discharge valve on the dust-catcher and admitted air probably in an amount to form with the gas from the furnace a highly explosive mixture. When this reached the stoves it exploded and shattered every explosion door on the whole gas system.

I remember another case where something of the same kind happened when a gas main, several hundred feet long, with many leaky explosion doors on it, was torn all to pieces. These instances and many others like them show that an explosion door of the usual kind is often the cause of explosions and is never of any use in case of a true gas explosion, especially if there is a good deal of hydrogen present.

During the past thirty years there has been a constant improvement in the iron and steel business in many directions. One notable instance has been in more refinement in designs of heavy machinery. Forty years ago there was a great deal of difference of opinion as to how much nicety of design was warranted in heavy rolling-mill machinery. Machine-cut gearing was felt by many to be an extravagance, and rough-and-ready coupling-boxes were thought to be good enough.

In the case of heavy reversing mills we can all remember the piles of spindles and coupling-boxes that were stacked around the mill each year and also the rough cast pinions that lasted less than six months. After a few mills were equipped with cut gears running in non-adjustable bearings held solidly in position and continuously oiled, and various types of flexible couplings were developed, the pinions and couplings showed almost entire elimination of backlash which was accountable for most of the wear and breakage of roll

spindles and pinions, as well as wear and trouble in the engines. These cut gears and new types of flexible couplings also showed an amazing decrease in cost of maintenance, and they were rapidly adopted. Much progress has also been made along metallurgical lines by extensive research work constantly carried on by many organizations, and this metallurgical work is being carried on more extensively at the present with very helpful results to the metal trade.

The last half century has been a wonderful one and we should be thankful that we have lived in it. We congratulate young members that they will live in a still more wonderful one and predict that they will do well their part in working for the good of mankind.

PROGRESS IN COAL-MINING IN THE PITTSBURGH DISTRICT*

By E. A. Holbrook†

Of what use is coal to a breed of hardy pioneers and woodsmen skilled with the ax and surrounded by primeval forests? It is not strange, therefore, that the immense deposits of coal in Western Pennsylvania were of little interest in our early history. In 1768, the Penn proprietors, with rare foresight bought from the chiefs of the Six Nations all the coal fields of southwestern Pennsylvania for about ten thousand dollars. Later, in 1784, they granted the privilege to mine coal from "Cole Hill" opposite the city (now Mount Washington) for £30 per lot "to dig coal as far in as the perpendicular line falling from the summit of the hill." The mined coal seems to have been wrapped in rawhide, slid down the hill, and used in the town as domestic fuel.

In 1794 came the first steam-engine to Pittsburgh, using coal, and, in 1797, the first glass plant in the United States to use coal as a fuel was started on the south bank of the Monongahela River opposite the city. From this time on, each decade reveals the growth of Pittsburgh as a manufacturing center—growth based largely on cheap coal as fuel for heat and power. Thus, in 1854, there were in Pittsburgh 17 large rolling-mills, 38 foundries, 20 glass factories, 20 engine shops and machine-shops, five large cotton factories, and four flour-mills; in all, there were more than one hundred steam-engines in operation at or near the city. The consumption of coal here was nearly half a million tons per annum.

You will notice that no mention is made of blast-furnaces in Pittsburgh. It was with some surprise that I found that coke from coal did not figure in the manufacture of pig-iron in Western Pennsylvania up to about the time of the Civil War. The early blast-furnaces of the region, situated in the Connellsville basin and other interior points, used wood charcoal as a fuel. Early blast-furnaces attempting the use of coke as a fuel were at Uniontown in 1838 and at Johnstown in 1854. In Pittsburgh the first use of coke to manufacture pig-iron was in 1859 and 1860 at the Clinton furnace.

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From the early 'seventies on, coke made in beehive ovens rapidly displaced charcoal. The annual report of the Secretary of Internal Affairs of the Commonwealth of Pennsylvania, 1877-1878, part 3, page 440, quotes from an earlier report by John Fulton, "It is also manifest that coke is destined to become the leading fuel for blast-furnaces; and to retain this position from its almost inexhaustible source of supply, its calorific efficiency and its continued economy." It is, therefore, of more than passing interest that our great iron and steel industry was founded, not because of our great coal deposits, but because of local iron ores and an apparently inexhaustible virgin forest. However, this forest disappeared long ago, and we would have lost our iron and steel supremacy had it not been for the accidental location over the greatest and best seam of coking coal in the world.

The history of the Engineers' Society of Western Pennsylvania covers only 50 years, and yet this period virtually has seen the development of the coke industry of Western Pennsylvania to a place where its beehive-oven coke was the standard of the world, and reached a production of over 27,000,000 tons in 1916. In the few short years since this time it has witnessed the development of the by-product coke industry until to-day more than 73 per cent. of our coke comes from the by-product ovens.

Coal was shipped down the rivers at an early date. In 1802 a shipment went down the Ohio, and, in 1817, successful regular shipments were floated by barges to lower river ports. There the barges were sold or broken up and the crew returned home by land or by river. This caused the first boom in our coal business and even land values increased in Pittsburgh. Through the years, however, this method proved slow and uncertain. In 1858, William Hughey Brown collected a tow of 12 coal boats loaded with 230,000 bushels of coal and started them down the river with a steamer tow. The venture succeeded and "there was now no limit to the future coal industry of the Pittsburgh district."

Our railroad coal trade developed later than the river trade. In 1843, the Pennsylvania Canal (Western Division) carried east 973 tons of Allegheny Mountain coal. In 1853, the first coal was shipped east over the Pennsylvania Railroad. Taylor, writing in 1855,* said

*Statistics of Coal, by R. C. Taylor. Ed. 2, 1855. Moore, Philadelphia.

"It is not probable that Pennsylvania bituminous coal will ever acquire an eastward market so long as the anthracite fields remain unexhausted."

During the Civil War, Western Pennsylvania coal forced its way to the lake ports and as far west as the Chicago market.

I have outlined briefly our coal history in order to present a picture of the industry when our Society was founded in 1880. At that time we had been developing coal for a hundred years, in manufacturing, in river and rail trade, and in domestic use, until Western Pennsylvania was producing about 16,000,000 tons a year. In the seven counties surrounding Pittsburgh we produced about 4,000,000 tons and employed about 7300 men. There were in these counties 216 mines in operation, with an average tonnage of only 46,504 tons. They worked 157 days during the year, 10 hours a day. The average mining price was 49.57 cents a ton, more often reckoned at two to three cents a bushel of 76 or 80 pounds. It must be remembered, however, that this mining price was paid, not on the coal as mined, but only on the coal which was oversize on a 1½-inch bar screen. The 20 to 40 per cent. of nut and slack passing this screen was discarded and not paid for, and generally was thrown into the gob or into the river. The average yearly earnings of each miner amounted to $337.07.

The coal-mines of Western Pennsylvania were practically all small drift or slope mines, developed on the single-entry system. A report on the Bituminous Coal-Mines of Pennsylvania by a State Commission (*Engineering and Mining Journal*, October 30, 1875, p. 429) classified the systems of mining as follows, (1) no system, (2) block system, (3) double-heading system. Under (1) they describe the haphazard driving of single entries, and rooms at right angles from these entries. "Two rooms driven in opposite directions from neighboring entries have to be driven full length and meet before any circulation of air is provided. . . . The air is more or less loaded with noxious gases, in which it is difficult to keep lamps lighted. . . . Frequently foulness of the air suspends work for some days." Under (2) they state that the general system in the counties around Pittsburgh is the block system. Here single entries are driven 150 to 500 yards apart and other single entries driven at right angles to the former 100 to 300 yards apart. The ideal mine plan would

thus be like a checkerboard. They complain of the absence of ventilation until the block has been cut on two sides. Rooms were opened on one or both sides of the entry. This in effect was a single-entry system. "It prevails generally in Allegheny, Westmoreland, Washington and Fayette counties." Under (3), which is the ordinary double-entry system used to-day, they state "Not yet in general use." The annual report of the state Bituminous Mine Inspector, for 1878, describes and diagrams the new double-headed entry system, evidently uncommon and most advanced mining practice.

A number of methods were used for working the rooms in the mine, varying according to the position of the track in the room. These methods were alike in that the rooms were driven wide and the pillars narrow. This meant a large loss of pillar coal. The mine inspector reports that in abandoned mines fully a third of the coal has been lost. Selwyn M. Taylor, writing* of the period prior to 1880, says:

"There was little or no careful scientific mining done in this district, and few of the operators of mines knew anything of the inside of their mines, trusting the work to the mine boss, who very frequently abandoned large bodies of coal because of some minor difficulty."

The chief complaints at the time concerned ventilation. The Bituminous Coal Mine Inspection Act of 1877 had just become a law, and was commonly known in this district as the ventilation law. The mechanical ventilator or ventilating fan, although much used at the time in England, had not yet made headway in our bituminous fields. Ventilation was commonly by a furnace built at a shaft or slope bottom, but sometimes by exhaust steam from underground pumps and haulage engines. Many mines depended on natural ventilation.

Altogether, in 1879, there were in Greene, Washington, Fayette, Somerset, Bedford, Westmoreland and Allegheny counties 248 coal-mines, 216 of which operated during the year. Of these, 101 had natural ventilation, 97 had furnaces, 11 had steam exhaust, and seven had fans. If one compares underground conditions of fifty years ago with those of to-day, progress in ventilation stands out like a beacon.

The average mine of 1880 had light iron rails on the main roads, with wooden rails in the rooms. The miner pushed his coal-car to

*Proceedings, 1894, v. 10, p. 172.

and often from his room, and the main haulage was by mule, sometimes in string teams of three or more animals.

Commonly, a single miner worked alone in a room. It was his place until it was finished. He undercut the coal with a pick on the bearing-in band (about two feet above the bottom), sheared and wedged down the coal above, and then the coal below the band. He loaded his coal, kept the place timbered, and laid his track. In short, he was monarch of his working place. If he had a son, the son worked with him. Several of the accident reports of the period mention sons, thirteen or fourteen years of age, working with the father. In this arrangement, when the man got three cars, the boy got one, called the "boy wagon." The lists of names of miners show that in every case they were of British or northern European origin. The southern European was not generally introduced into our mines until the period of the 'nineties.

Partly on account of ventilation difficulties, powder was little used, excepting for entry driving. There were no mining machines. Lighting was generally by open black oil lamps. In short, in fifty years we have progressed in coal-mining in this district from individual muscle power, working under conditions we know to-day to be inefficient and unhealthful, to a place where electrical power and many other inventions, guided by men working under generally comfortable surroundings, produce the bulk of our coal. Each decade since 1880 has added its own increment to bring about our present-day position.

Briefly, the decade beginning with 1880 first felt the provisions of the state Bituminous Mine Inspection Act. This resulted in a general adoption of mechanical ventilation. It saw the general introduction of the compressed-air mining machine of the Harrison type and the use of powder as an aid in mining the coal. It saw the general adoption of the double-entry system in new mines, and the replacement of animals, for main haulage underground, by rope haulage (either single, endless or tail rope), as well as a few small steam locomotives.

The decade beginning with 1890 is remarkable for the introduction of electricity underground. This was used first for signaling, then for lighting, then for driving pumps, then for trolley locomotives to haul coal, and finally for successful mining or coal-cutting

machines. During this decade, the compressed-air locomotive made its appearance underground and would have developed to a greater degree had not electrical haulage, accompanied by better ventilation, generally been found more economical.

The decade beginning with 1900 saw a remarkable growth in the size of individual mines, and we began to think in daily tonnages in thousands, rather than in hundreds of tons. Shaft mines became common. Electricity became the generally accepted underground power. New systems of mining to fit the new appliances were tried out, resulting in the development, about 1910, of the so-called and now common Connellsville or block system of narrow working on the advance and a general wide retreat, resulting in more than 90 per cent. recovery of the coal. Safety lamps became common in our more gassy mines, and the acetylene lamp displaced the "Improved Sunshine Oil Lamp."

This decade is remarkable, too, for the considerable number of major mine disasters, leading to the formation of the United States Bureau of Mines, and to its subsequent work on mine safety. The period also saw the organization and development of large companies with many mines in place of the many single-mine companies.

The decade beginning with 1910 saw the application of electricity to new uses around the mines. We had previously used it underground; now we began to replace surface steam-driven hoisting-engines and ventilating fans by electrically operated units. This led, in this and the succeeding decade, to the general abandonment of the great individual steam power-houses at the individual mines and the substitution of purchased electrical power, generated at a distant central plant. For a coal-mine to purchase power from the outside was, to use the words of one mine superintendent, "like carrying coals to Newcastle." The period is remarkable for the coming, in 1916, of the workmen's compensation law, effecting a revolution in the relations of employer and employee—a law the far-reaching effects of which we have not yet had time to realize. During this period, safety became an organized force in the industry, and appliances and machinery emphasizing human safety as developed in this coal-mining field have shown the way to other industries.

Most of all, this was the period of the World War, when the average citizen first realized his dependence on coal. President Wil-

son said, "To the coal miner, let me say, the work of the world waits upon him; if he falter or fail, armies and statesmen are helpless." It was all so recently in our minds that I add only that it saw an unprecedented demand for coal, with consequent high prices and the opening of hundreds of new mines, enough to make our potential yearly production one billion tons instead of the half billion normally required.

And for what is the past decade remarkable? We are still too close to it to have a proper historical perspective. So far as mining is concerned, the outstanding feature is the development and adoption of mechanized mining, meaning by this the development of machinery which does away with the necessity of the miner shoveling the broken coal at the face into the pit car. Experimented with for many years, its use has been increasing annually at the rate of from 50 to 75 per cent., until many companies are mining a considerable part of their coal without hand labor at any place. It is being adapted to conditions thought impossible for it a few years ago. I predict that it will go through the same evolution as did the electrical coal-cutting machine, and in time will shovel the bulk of our coal.

This decade witnessed remarkable progress in coal preparation in this district. Perhaps the first coal washer here was erected in 1882 at the Monastery mine of the H. C. Frick Coke Company, Latrobe, Pa. (a plunger jig having a capacity of 500 tons in 10 hours). From that time on coal-cleaning plants came and went, and in general were most successful where a very clean coal was needed for coking purposes. In the past few years coal-cleaning plants preparing coal for the general market have been built, and to-day the Pittsburgh district has the largest and most modern coal-cleaning plants in the world.

This decade is remarkable, I think, for the increased efficiency with which coal is used, for the coming of competing fuels, and for the disappearance of the individual coal-mine steam plant in favor of the central electrical power-plant. And yet, if we go to the official statistics, we find that to-day coal is still generating 65.3 per cent. of our power.

In all this advancement, the Engineers' Society of Western Pennsylvania has had an integrated part. The first technical article on mining practice presented before our Society was by C. F. Scott

in 1891. The title was "Description of an Electric Coal-Mining Plant."* Since that time our volumes reveal a steady flow of papers and discussions detailing important progress in mining in this district. Perhaps the best proof that we have continued to be the center of bituminous coal-mine progress is the steady stream of foreign coal-mine officials and students to visit the region.

Finally, what of the ups and downs of our coal industry in the past fifty years, for, after all, prosperity is the issue! Is our present slack demand for coal something new or is it part of a recurring cycle?

Fifty-three years ago the mines of Allegheny County mined 1,104,276 tons a year and employed 3120 men. Last year (1929) Allegheny County produced 16,590,302 tons with 14,208 men employed—an increase of 1400 per cent., with an increase in personnel of 355 per cent. This represents progress.

A little later (1878) an operator complains that high freight rates are ruinous and there seems to have been a state tax (amounting to about three cents a ton) that agitated the industry. By 1880, the industry was booming again, with many new mines opening in Westmoreland and Fayette counties.

In 1885, there was a disastrous strike in the Connellsville district, connected partly with the employment of Hungarian women around coke-ovens. It appears that they were really employed by their husbands who had piece-work contracts. The result was a law forbidding this employment to women.

In 1885, natural gas was piped to the Pittsburgh district and the coal industry seemed doomed, good Pittsburgh district coal land selling for $50 an acre. The use of gas affected the local coal output by 2,000,000 tons that year. Somehow the industry slowed up for a year or two only and before the panic of 1893 there was much apprehension on account of the shortage of labor to mine the coal for which a demand existed. Labor was imported from southern Europe, and this was a troubled period of many strikes.

The Pennsylvania bituminous coal industry suffered with the rest of the country during the depression of 1893-1896, but by 1900 was again going ahead with increased tonnage. Another marked depression came in 1907 and another in 1914, to be followed each

*Proceedings, 1891, v. 7, p. 38.

time by renewed activity and a growth in tonnage, generally accompanied by strikes.

We realize now that the enormous growth and expansion of our coal industry during and following the World War was abnormal, and but a repetition of the cycles which the industry has been going through for the 50-year period under discussion. The depression of the industry caused by the strike of 1927 was but a recurrence of several other like periods. Even the present competition with natural gas had its counterpart back in 1885, and the earlier generation likewise had trouble over freight rates.

The point I am after is this. To-day we have in Western Pennsylvania increased our coal production at least nine-fold in the past 50 years. It has not been a peaceful, easy, steady growth. Handicaps from strikes, from business depressions, from competing fuels, from railroad freight rates, and from labor shortage and excessive taxation have been met before. They have for a time handicapped and depressed the industry, but out of the trough of each depression has emerged a crest of increased tonnage and more scientific methods. We can not see these pictures when we are in the midst of events, but looking back over 50 years they stand out clearly and provide a sure forecast for the future. To-day more than ever I am convinced that when we speak of American civilization and industrial Pittsburgh, Coal is and will remain our King!

A HALF CENTURY OF ELECTRICAL ENGINEERING*

By Charles F. Scott†

INTRODUCTION

Power—engine power in the last century, electric power now—underlies the engineering and industrial development of Western Pennsylvania, and indeed the new world in which we live.

The iron industry began here about 1800 at the gateway where the Allegheny and Monongahela converged westward travel and the Ohio afforded ready transport for hardware and heavy iron products, difficult to bring over the mountains. Here men of courage and initiative employed the traditional methods and the inherited skill of centuries; but there entered a new factor—the infant steam-engine. "Cramer's Pittsburgh Almanack" for 1813 chronicles "a most powerful steam engine" of 70 horse-power at Penn Street and Cecil Alley for operating *"a Rolling-mill, a Slitting-mill, and a Tilt-hammer"* for making nails and various tools and utensils.

The shift from muscle to mechanical power means much when output is measured in tons; the steam-engine converted the iron industry, with its little forges and furnaces, to new methods and new magnitudes.

CONDITIONS FIFTY YEARS AGO

The fiftieth anniversary of our Society commemorates a significant period. The very fact that in a district, world famous for industrial achievement, the engineers had come together, indicates a new consciousness and a new attitude—a formal transition from individual secretiveness to common endeavor.

The engineering spirit was awakening. Shortly after our first meeting in January 1880,‡ the American Society of Mechanical Engineers was formed, and a few years later the American Institute of Electrical Engineers. In two decades the half dozen engineering

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‡The paper presented at the first meeting was by William Metcalf (Proceedings, v. 1, p. 1) on "Why Does Steel Harden?" It recounts the facts which he and Professor Langley had found in five years' research and concludes that "if any are in doubt as to what is the correct answer to this momentous question, we can only say that we are all in the same boat, for if you do not know, neither do we."

schools of 1860 had increased to fourscore; men of scientific and engineering training were ready to accelerate the progress by which the sturdy pioneers of the mill had brought the Pittsburgh region to industrial pre-eminence.

The industrial pioneers of 1800 little suspected the revolutionary significance of the steam-engine; nor did the new engineers of 1880 realize that a new power—the forerunner of a second industrial revolution—would soon be at their service.

In December 1879 (a few weeks prior to our first meeting) the *New York Herald* announced Edison's new incandescent lamp; in March the Allegheny County Light Company was chartered and soon supplied arc-lamps. The New York Edison Company inaugurated public service for incandescent lighting in 1882. Pittsburgh began lighting in 1884 with a 75 "light" generator (not 75 kilowatts, but 75 lamps of 16 candle-power). It was a great achievement to carry the output of the engine by wires, available for light and heat and mechanical power; to make energy a commercial commodity was a momentous event.

At a meeting of the Society in 1881, Jacob Reese presented a paper, "Electricity; What It Is, and What May Be Expected of It."* Reese offers a very interesting theoretical discussion concluding thus, "Electricity—What is it? Why, it is dynamic caloric." Stating that boilers and engines and dynamos deliver only five to ten per cent. of the static caloric of coal, he predicts the direct production of electricity from coal by a process so simple and cheap that "aerial navigation will be developed in the near future to be one of the greatest enterprises of the world" and that electricity would be universally used for light and heat and motive power. He adds, "Considering the difficulties of transmitting steam power to a considerable distance, and the comparative great cost of running small engines, it is more than likely that electricity as at present generated will be found economical for driving small motors." He refers to tests showing that the gas consumed in an Otto gas-engine driving a dynamo could produce better and cheaper light than when used in ordinary burners. Reese was fundamentally right; what he did not foresee was the internal combustion engine and the superior quality of electric light and power.

*Proceedings, v. 1, p. 264.

ELECTRIC SYSTEMS AND LOCAL SERVICE

The Edison three-wire system was, by the cost of copper, limited to a radius much less than a mile. Pittsburgh contributed a new method. George Westinghouse sponsored the alternating system in which small currents economically transmitted at high voltages are transformed to low voltage for use. He acquired the rights, methods were modified, he personally contributed by design and invention, apparatus was developed and tested by his engineers (Stanley in Great Barrington, Shallenberger and Schmid in Pittsburgh). The first plant began operation at Buffalo on Thanksgiving Day, 1886, and with it came the era of long-distance transmission.

But the 130-cycle, single-phase service was suited only for incandescent lighting. Then came another great step—the induction-motor and the polyphase system. Westinghouse acquired the Tesla patents and pioneered the development of electric power as it is to-day. It brought order out of chaos. Different generators and circuits had been required for direct current and for alternating current, for incandescent lamps, for arc-lamps, and for railways. All were inherently small. Now enormous polyphase generators operating in parallel in the same station or remote stations supply a universal service through nation-wide networks of transmission circuits.

The story of electric power in Pittsburgh reads like a fairy story—the contribution of fundamental methods and inventions, the building of a great electrical manufacturing industry (See Fig. 15), the growth of local electric power-plants down-town, in Allegheny, on the South Side, in the East End, and in Wilkinsburg, Braddock, McKeesport, Verona, and Sewickley, and then the merging of a hundred and more into the single Duquesne Light Company system with capacity of half a million kilowatts and the subsequent connection in a superpower system extending from Chicago to Florida. (See Fig. 9.)

Evolving from an engineering experiment and a luxury, electricity speedily became a great public utility. Roughly, twenty-five years of development of apparatus and pioneering in its application were followed by twenty-five years in which the use of electric power has increased twenty-fold. (See Fig. 16.)

Recently, I asked a factory manager what was the outstanding industrial service of electricity. He replied, "My answer may surprise you; it is lighting. In my early days as a machinist we used the

lard-oil lamp with open flame and not much work was done on winter afternoons. Second to lighting is the electric crane and the hoists for handling material."

ELECTRICITY IN THE STEEL INDUSTRY

In our steel-mills, arc-lighting began at the Edgar Thomson works in 1881, aiding 24-hour operation in large areas and with dangerous processes. A decade later, motors began to replace small engines and then undertook their arduous task on cranes and hoists in severe and exacting service. The early 75-kilowatt power-plant had increased a hundred-fold in size when in 1905 (midway in our 50-year period) two 1500-horse-power motors at the Edgar Thomson works initiated the electric driving of main rolls. Motor-driven reversing rolls of 5000 horse-power came a year later at South Chicago. Mill men were slow to believe that a motor could possibly replace a gigantic reversing engine; but the transition came with accelerating rate. A recent tabulation gives 1800 motors, ranging from 300 to 9000 horse-power, and aggregating 2,250,000 horse-power, driving American rolls. (See Fig. 11.)

The motor does what the engine did and it does also what was impossible for the engine—it gives a rotary instead of a reciprocating source of power. There is less wear and tear, decreased repair, greater ease and flexibility of control, resulting in increased output at lower cost.

In the early days the electrician about the mill trimmed arc-lamps and repaired armatures and controllers; but he soon became the man to go to in times of trouble. He solved problems but he also formulated new ones, analyzed conditions, and proposed new methods. Electrical engineers in the industry came together for common counsel; they formed an association (the Association of Iron and Steel Electrical Engineers, with headquarters in Pittsburgh), thus breaking down isolation, exclusiveness, and secrecy, and they combined their experience and abilities for the solution of their common problems and the advance of the industry. The electric motor transformed mill operations and methods; the electrical engineer has created new spirit, new vision, new initiative, new confidence, and a new era of progress in the industry itself.

MINING AND TRANSPORTATION

Coal-mining is one of Pittsburgh's historic major industries. In 1891, I presented to the Society a paper describing a year's operation of a mine in the First Pool with multiple-drill undercutting machines of a new type operated by induction-motors in the design of which I had participated. This was, I believe, the first commercial operation of induction-motors. Familiar with early mining conditions, I was recently thrilled on viewing the moving picture of the 100 per cent. mechanized mine at Wildwood, where the old-time miner with pick in hand, with smoking lamp in his cap, undercutting and drilling and laboriously loading cars to be pushed by hand or drawn by mules, is no more. Electricity lights, undercuts, drills, ignites the blast, loads the coal, hauls and dumps it, and pumps and ventilates and dusts the mine.

On my first visit to Pittsburgh in 1888 I had a long, long trip by horse-car out Penn Avenue to see the new East End electric light station with its half dozen engines belted to alternators aggregating some 250 kilowatts. Later I rode in an electric car up a steep grade (instead of the old "incline") to Mount Oliver and Knoxville. Current came through a flexible cable from a little carriage which rode on the trolley wire. I was told that operation was more dependable when a boy on the car pulled the overrunning trolley wheel with a rope. About the same time an electric road in Federal Street, Allegheny, used underground contacts and then overhead trolley as the cars negotiated Observatory Hill. Electricity was given a task which horses were least able to perform—a task too great, in fact, for the electrical devices of those days. But electrical development was rapid. Within a few years three cable lines toward the East End had been installed and discarded and the whole Pittsburgh district was covered by a network of electric lines linking a hundred towns into one great united community. Previously, nearly everybody lived within walking distance of his work or of a suburban railway station; but the electric service covered hills and valleys with homes. We now have highways and automobiles and buses, but for several decades the electric car had no competitor in the transportation and unification of greater Pittsburgh. Scores of local horse-car lines and early electric lines now form one vast electric railway system. The railway motors in general use to-day are patterned after the No. 3 Westinghouse

motor, with its slotted armature, single reduction gears and inclosed form. In heavy traction the single-phase system proposed here by B. G. Lamme acquired prestige through the electrification of the New York, New Haven and Hartford Railroad, and is now being installed in the gigantic program of the Pennsylvania Railroad.

Another Pittsburgh contribution to electric power must be cited. Westinghouse was fascinated from boyhood with the idea of a rotary steam-engine. His heroic endeavor to produce one culminated in his adoption and development of the turbine principle and the installation of the first central-station turbo-alternator in America—a unit of 1500 kilowatts thirty years ago at Hartford, the forerunner of modern power production with units a hundred times as great. (See Fig. 8 and 13.)

COMMUNICATION

Andrew Carnegie relates interesting incidents of his service as a telegraph messenger boy in the 'fifties. Later (in 1874) the Central District and Printing Telegraph Company (acquiring numerous private lines connecting residences, offices, and factories) established a new kind of service for person-to-person communication carried on by messenger, by printing telegraph, and by delivery boy. This new system, this endeavor to make a district a neighborhood, was soon simplified by further invention, and four years later (52 years ago), a telephone exchange was installed in Pittsburgh. What an opportunity for messenger boys if the old system attempted to handle Pittsburgh's million calls a day! (See Fig. 1-4.)

In 1897, Bennett and Bradshaw, Pittsburgh students, took wireless telegraphy as their thesis topic; their professor (Fessenden*) became interested, appreciated difficulties, devised an electrolytic detector and proposed undamped waves (now universally used) from high-frequency generators.

A few years later Marconi's three dots spanned the Atlantic. Then came broadcasting. Out in Wilkinsburg victrola music from Conrad's miniature sending station to listening amateurs gave the vision. A few months later a new public service was inaugurated by

*In the Western University of Pennsylvania, now University of Pittsburgh. Professor Fessenden was secretary of the Engineers' Society of Western Pennsylvania during the years 1897-1900 while he was pioneering in wireless telegraphy; Bennett is now professor of electrical engineering at the University of Wisconsin, and Bradshaw is manager of engineering at the Westinghouse works at Newark. Kintner (past president of this Society) was Fessenden's assistant and later succeeded him at the local university before entering industry.

KDKA in its pioneer broadcasting of the returns of the presidential election just 10 years ago. It has already revolutionized campaign methods; it is ranked a close second to the newspaper as a factor in daily life. And again Conrad working with the amateurs discovered that the rejected short wave had vast superiority for long-distance service, such as talking with Byrd at the South Pole. (See Fig. 14.)

One may well ponder over the question of whether electric power or electric communication—one serving the physical, the other the intellectual—makes the greater contribution to our modern life.

IN THE HOME AND ON THE HIGHWAY

One could reminisce endlessly in portraying the particular applications of electricity. Most surprising it is to find in how many ways it has become indispensable. In the home, electricity replaced oil lamps and flickering gas; then followed fans and cleaners, flat-irons and toasters, washing-machines and sewing-machines, percolators and clocks, ranges and refrigerators, pads and hot plates, water heating and house heating, temperature regulators and telephones, sunlight lamps and radios. The invisible servant—ever ready, untiring and at lessening wage, carrying old burdens and rendering new service in city apartment and country house—contributes to the joy of living in 20,000,000 homes through comforts and luxuries impossible in the king's castle of old. (See Fig. 1-2, 5-7.)

Consider the automobile. You say electrics are few and gasoline is universal; yet electricity enters into its making and its motion. Electrically made aluminum developed in Pittsburgh and electrical alloy steels reduce weight and cost, while electrically produced carborundum (an abrasive invented by Acheson near Pittsburgh) cheapens its manufacture in motor-driven factories where electricity lights and welds and tempers and anneals. (See Fig. 12.) On the car, electricity from 25,000,000 electric plants lights and starts and ignites. The momentary capacity of starting motors rivals the 30,000,000-horse-power electric power load of all our industries; and concrete highways contain electrically made cement.

ELECTRICITY SUPPLANTS MUSCLE, SKILL, AND JUDGMENT

Benjamin Franklin was chagrined because interesting electrical experiments had enabled him "to produce nothing in this way of use

to mankind", but now we may evaluate the social significance of electricity in saving man-power and contributing to human welfare.

The most vivid impression of my first visit to Homestead nearly forty years ago was the charging of the open-hearth furnace. Three strong men with a sort of crowbar arrangement put the heavy materials in the lake of molten steel—the severest muscular work I had ever seen, and in the heat of the glowing furnace. Now a man operating controller levers does ten times the work. On a later visit, a ladle with 50 tons of molten steel was lifted and shifted by an electric crane; a few minutes afterwards I stepped aside for a laborer carrying a plank, and working harder than the man on the crane.

We marvel at the electrical operation of the coal-mine, but the human transformation is most significant. Man is relieved of a most arduous type of toil. The requisite in the modern miner is not mere muscle, but ability to operate machinery.

Motors end the age-long burden of toil and give to our workers an average power of scores of old-time slaves, more effective because of concentration and control. (See Fig. 10.) And electricity is a self-controlling agent. Witness the automatic telephone exchange and the automatic power-station. In the steel plant, adjustment and control by electricity transform the great rolling-mill into a gigantic automatic tool, of new precision and greater output. Now come separate motors for upper and lower rolls, and plans for continuous rolling made possible by new refinements in automatic control. Temperature electrically regulated insures definite quality. Electrical measurement and control are revolutionizing industrial processes, and at the street intersection electromatic control beats the traffic cop, as it can see four directions at once and does the right thing without getting rattled.

TOOLS, METHODS, AND MEN

Man is the tool-using animal; and, as the tool changes, its operator must change also. A recent Secretary of Agriculture said, "Could a farmer of Pharaoh's time have been suddenly reincarnated and set down in our grandfather's wheat field, he could have picked up the grain cradle and gone to work with a familiar tool at a perfectly familiar job." But the weary plowman and the man with the hoe of fifty years ago would be confounded to-day by sowing and harvesting machinery, by farm engines and tractors and trucks, and

by new mysteries on our half million electrified farms. Our mechanized and electrified industrial life calls for a new type of worker—for men who can manage machines. The village blacksmith is superseded by the omnicompetent garage mechanic. The functions and relations of worker, foreman, and manager have changed. With increased production have come higher wages and shorter hours. The Saturday half holiday was pioneered in Pittsburgh by the Westinghouse Air Brake Company in 1881.

Let us integrate our electrical equation with its myriad factors to get a perspective view. In the advance of man, definite stages or epochs are recognized. The use of fire, the bow and arrow, the invention of pottery, the domestication of animals, the use of iron—each contributed to life on a higher plane. The outstanding factor in historic time is the production of power. In plotting a curve of human progress the long level of many centuries changes into high ground as the activities of steam power of the nineteenth century are reached, but these are only foot-hills before the rising altitude of the twentieth century record. And these curves of activity in a score of fields, simultaneously with the shift from muscle to manufactured power, coincide with the increasing use of power in new ways that electricity provides.

THE NEW INDUSTRIAL REVOLUTION

If the engine, supplying only mechanical power within the radius reached by shafting and belts, produced an industrial revolution so far-reaching that even the moral revolution of to-day is the outcome of the new social conditions which it produced, then what may we expect in the new era of universal electric power—colossal, yet intimate and personal as it serves the individual. Current literature and daily experience picture the changes—industrial, economic, social, political, medical, moral.

Some writers point to a millennium of ample production, and distribution adequate to the needs of all; with abundant comforts and luxuries, with lightened tasks, with higher standards of living, universal education, and leisure for the finer things of life. Others deplore a mechanized civilization and see a Frankenstein's monster turning to rend us, confident that we can not continue to adapt ourselves to the changing conditions about us. In one book philosophers

and learned men ask "Whither Mankind";* in a sequel, scientists and engineers reply "Toward Civilization."† Some are mystified as to causes; a young student of economics and business when asked for the underlying condition making possible the changes he had portrayed replied "That is the economic mystery." A wider vision finds the answer in our new facility for doing things. Many thought our war-time activity was the peak, but so rapid was the advance in the next decade that it merited a special study concluded a year ago by a Hoover Committee with a two-volume report on "Recent Economic Changes."‡ The first subtitle in the report strikes the keynote, "The Speed Which Power Has Added to Production." In an early paragraph is this sentence, "Through the subdivision of power the unskilled worker has become a skilled operator." Yes, upon the skilful use of power, upon subdivided electric power, rests our increased production with its economic acceleration, its social readjustments, and its far-reaching economic consequences, extending even to tariffs and international relations.

In the past decade we used three times the total electric energy that was used in the preceding forty years. (See Fig. 16.) Public utilities are spending towards a billion dollars annually to increase facilities for supplying electric power.

In the past, our world was believed to consist of four elements, fire, air, earth, and water. Much less than fifty years ago the atom was the ultimate. Then x-rays revealed a hidden realm and electronics soon opened a new field for research and invention. As a typical result, Judge Gary at his desk in New York with a wave of his hand near a sensitive tube disturbs the equilibrium of infinitesimal forces, and thus starts the great motors of the gigantic Homestead mill.

PROBLEMS CREATED BY ELECTRICITY

Electricity has brought progressive problems. Fifty years ago technical difficulties were paramount—the translation of accumulated scientific knowledge into practical machines; then the problem of supplying them in a hundred useful ways and inducing the public to use them.

*Edited by C. A. Beard. 1928. Longmans, New York.

†Edited by C. A. Beard. 1930. Longmans, New York.

‡Conference on Unemployment. Recent Economic Changes in the United States. 2 v. 1929. McGraw, New York.

From the early incandescent lamps and telephones, coming in the category of luxuries, have evolved great public utilities whose major problem has shifted from machines and methods to public relations. Electricity gives to remote rivers, long idle and obscure, the power to raise new questions of national policy, of states rights and interstate relations.

So much has modern electrified industry contributed to prolific production and the lessening of labor, that new economic and social problems confront us. Through the ages men have struggled for the necessities; now we are confounded by superabundance. Men have longed for surcease from toil; now we suffer from unemployment, and know not how to use our leisure. Old methods and customs are inadequate. Research and technology develop new industries, but transitions are still abrupt and painful. We are unable to stabilize progress; we have not learned to harness prosperity.

Electricity, a factor in creating leisure—the gift of the engineer—aids also in leisure hours. Talking movies (electrically made and displayed), radio, and television with their mass production methods furnish means for entertainment, education, and culture. Electric light brightens the night for reading and study, for indoor entertainment, and for outdoor sports.

But increased hours may merely change leisure from a pastime to an obsession; undirected, it is misused. As working hours become fewer and more routine, leisure hours increase in number and in opportunity for constructive betterment, or for idle dissipation. Within a generation, leisure, not work, has become the dominant factor and the dominant problem in life.

Science and technology continually shift the scene; research and invention create new opportunities by which the mechanism of industry may contribute to well being and the satisfactions of life, but they are often lost through sluggish or inept economic and social readjustment. We may be likened to the people of a foreign land where missionaries brought wheelbarrows which the natives loaded and carried on their heads.

The story of man's ascent is the story of his tools; his means of doing things. New tools (bow and arrow, ax, plow, lathe, loom, locomotive, lamp, printing press, telegraph, motor, automobile, radio) change the modes of life. Tools and workers react. Men produce

new tools, and new tools develop new types of workers, thus for better or for worse reshaping their standards of living, economic, social, moral, cultural, and spiritual.

And the story of electricity in the past half century—in achievement and in anticipation—illuminates the verdict of Herbert Hoover that "Electricity is the greatest tool that has ever come into the hands of man." (National Electric Light Association Proceedings, 1924, v. 81, p. 122.)

DATA REGARDING ELECTRICAL DEVELOPMENT

The story of the development of electrical engineering during the past fifty years, particularly in its relation to the Engineers' Society of Western Pennsylvania, would be incomplete without statistical data indicating its rate of growth and its magnitude. Several of the companies which have been outstanding in their contribution to this development were requested to contribute information, and this they have done largely through charts and diagrams. While these deal principally with local developments, some indicate the development throughout the country.

The Bell Telephone Company, the Duquesne Light Company, and the Westinghouse Electric and Manufacturing Company, named in order of age, have contributed the facts and figures relating to their particular fields. Additional curves are presented from the *Electrical World*. Fig. 10 (modified) is from vol. 95, page 34. Fig. 16 was adapted by S. S. Wyer for use on page 64 of his "Study of Electric Light and Power Service, Prepared for Fuel-Power-Transportation Educational Service" (Columbus, Ohio, 1929). It has been slightly extended for the present paper.

A CHRONOLOGY OF THE TELEPHONE WITH SPECIAL REFERENCE TO THE PITTSBURGH DISTRICT

1874. The Central District and Printing Telegraph Company formed.

This company purchased and united a number of private telegraph lines, in Pittsburgh, which ran chiefly from mills to residences and railways.

Messenger service was established and the use of printing telegraph instruments was introduced.

1876. First complete sentence transmitted by telephone.

1878. Telephone introduced in Pittsburgh by the Central District and Printing Telegraph Company to supplement its existing services.

First telephone exchange in Pittsburgh opened in Room 6, First National Bank building, at the corner of Fifth Avenue and Wood Street.

Pittsburgh telephone directory issued, containing the listings of more than eighty subscribers.

1881. First underground telephone cable laid in Pittsburgh.

1884. Long-distance line opened between Boston and New York, 235 miles.

1891. Long-distance service established from Pittsburgh to Philadelphia and from Pittsburgh to Cleveland.

1892. Long-distance telephone line opened between New York and Chicago, 900 miles.

1898. Common battery method of operation introduced in Pittsburgh.

Batteries were located in the central office building and the use of the magneto crank for ringing purposes was eliminated.

1899. The Pittsburgh and Allegheny Telephone Company organized to furnish telephone service in Pittsburgh and environs.

1900. Loading coils put into commercial use.

Loading coils are inductances (copper wire on iron core) inserted in series with the line at periodic intervals of approximately 6000 feet to improve transmission by partially neutralizing the shunting effect of the inherent capacity between the line wires.

1913. The Central District and Printing Telegraph Company became the Central District Telephone Company.

1915. Transcontinental telephone line opened from Boston to San Francisco, 3600 miles.

Repeaters put into commercial use.

Telephone repeaters are two-way vacuum-tube amplifiers which are inserted in long-distance lines to step up diminishing signals. Their introduction made the transcontinental line practicable.

1917. Pittsburgh-Baltimore carrier circuit opened.

A carrier circuit is obtained by transmitting superaudible frequencies over a telephone circuit which is also carrying audible frequencies. Commercially, three two-way carrier channels can be obtained over a pair of open wires carrying one voice channel.

1918. The Central District Telephone Company became a part of the Bell Telephone Company of Pennsylvania.

1921. Deep-sea cable between Key West, Fla., and Havana, Cuba, 115 miles.

President Harding's inaugural address delivered by Public Address System to more than 100,000 persons.

1923. First dial telephone exchange (Montrose) opened in Pittsburgh.

The Pittsburgh and Allegheny Telephone Company's physical property purchased by the Bell Telephone Company of Pennsylvania, giving unified service to Pittsburgh.

1925. Telephone cable completed between New York and Chicago. Commercial transmission of pictures by wire.

1927. Commercial transatlantic telephony by radio.

First transatlantic call out of Pittsburgh to London on January 29, 1927.

First public demonstration of television by wire and radio.

1929. Demonstration of television in color.

Commercial ship-to-shore service.

1930. Commercial telephone service to South America and Australia. Demonstration of two-way television.

CHRONOLOGY OF THE ELECTRIC LIGHT AND POWER INDUSTRY IN THE PITTSBURGH DISTRICT

1880. First electric light company.

Allegheny County Light Company chartered.

The first power-station of this company was constructed a short time afterwards in Virgin Alley on the site now occupied by the Hardy and Hayes Building.

First Brush arc generator installed at works of Westinghouse Machine Company, Twenty-fifth Street and Liberty Avenue.

This machine furnished current for lighting the Pennsylvania Railroad yards, the lights being mounted on sixty- to ninety-foot poles scattered at intervals.

1882. Second electric power-station built. The Electric Light and Power Company was organized with its station at Diamond Street.

1884. The first incandescent lamp in Pittsburgh was installed in a restaurant at 52½ Fifth Avenue.

1885. The Pittsburgh Light Company was incorporated to serve the South Side. This company constructed its power-plant at Sarah Street.

1886. Alternating current introduced. Three hundred incandescent lamps in Lawrenceville supplied from an alternator in Garrison Alley, two miles distant, demonstrating the practicability of high-voltage alternating-current transmission then adopted by George Westinghouse.

The Allegheny County Light Company constructed a new station to serve the city of Allegheny with arc-lights.

The East End Electric Light Company was organized, and operated a generator in the basement of a confectionery store at 6202 Penn Avenue, from which was supplied street lighting in the East End district. This company later supplied alternating current from the Broad Street station.

1887. Alternating-current generators—the first commercial alternating-current generators in the Pittsburgh district, made by Westinghouse—were installed in the Allegheny County Light Company's plant in Virgin Alley, now Oliver Avenue.

1889. First electric motors for industrial use in the Pittsburgh district put in service.

1896. The East End Light Company was merged with the Allegheny County Light Company. Following this, electric companies operating in Wilkinsburg, Rankin, McKeesport, Oakmont, Verona, Bellevue, Emsworth, Ben Avon, South Hills and other districts were consolidated into a single operating unit in the Allegheny County Light Company.

1903. The Duquesne Light Company was organized and constructed a gas-engine plant in the East Liberty district.

The Brunot Island power-plant was built by the Pittsburgh Railways Company. It was the first power-station in Pittsburgh to contain steam-turbines. The first steam-turbine was a 3000-kilowatt unit.

1906. The first electric furnace in Pittsburgh, and one of the first in the United States, was installed in the works of the Firth-Sterling Steel Company at McKeesport and supplied with power from the Rankin plant of the Allegheny County Light Company.

1912. Duquesne Light Company merger.

The properties and franchises of the various companies in the Allegheny County Light Company group were merged with, and under the name of the Duquesne Light Company. Other mergers and acquisitions followed until to-day the Duquesne Light Company is the surviving company of some 150 independent companies originally organized in the district.

1913. Reconstruction of Brunot Island power-plant.

The Brunot Island power-plant was reconstructed, the smaller turbines previously in service being removed and five 15,300-kilowatt units installed in their place.

1920. Operation of Colfax power-station begun.

The first unit of the Colfax power-station, located on the Allegheny River, about 12 miles from, and northeast of the business center of, Pittsburgh, having a capacity of 60,000 kilowatts, was placed in operation. The present capacity of the Colfax power-station is 262,500 kilowatts.

1924. Completion of high-tension, 66,000-volt transmission ring around Pittsburgh district.

This transmission ring completely encircling the Pittsburgh area is about 89 miles in circumference. With its connections, it comprises 130 miles of transmission lines carried on steel towers.

1930. Construction of James H. Reed power-station.

The first unit of this station, with a capacity of 60,000 kilowatts, has just been completed. This station is laid out for an ultimate capacity of 360,000 kilowatts. It is located adjacent to the Brunot Island station, on Brunot Island in the Ohio River, about 1½ miles west of the business center of Pittsburgh.

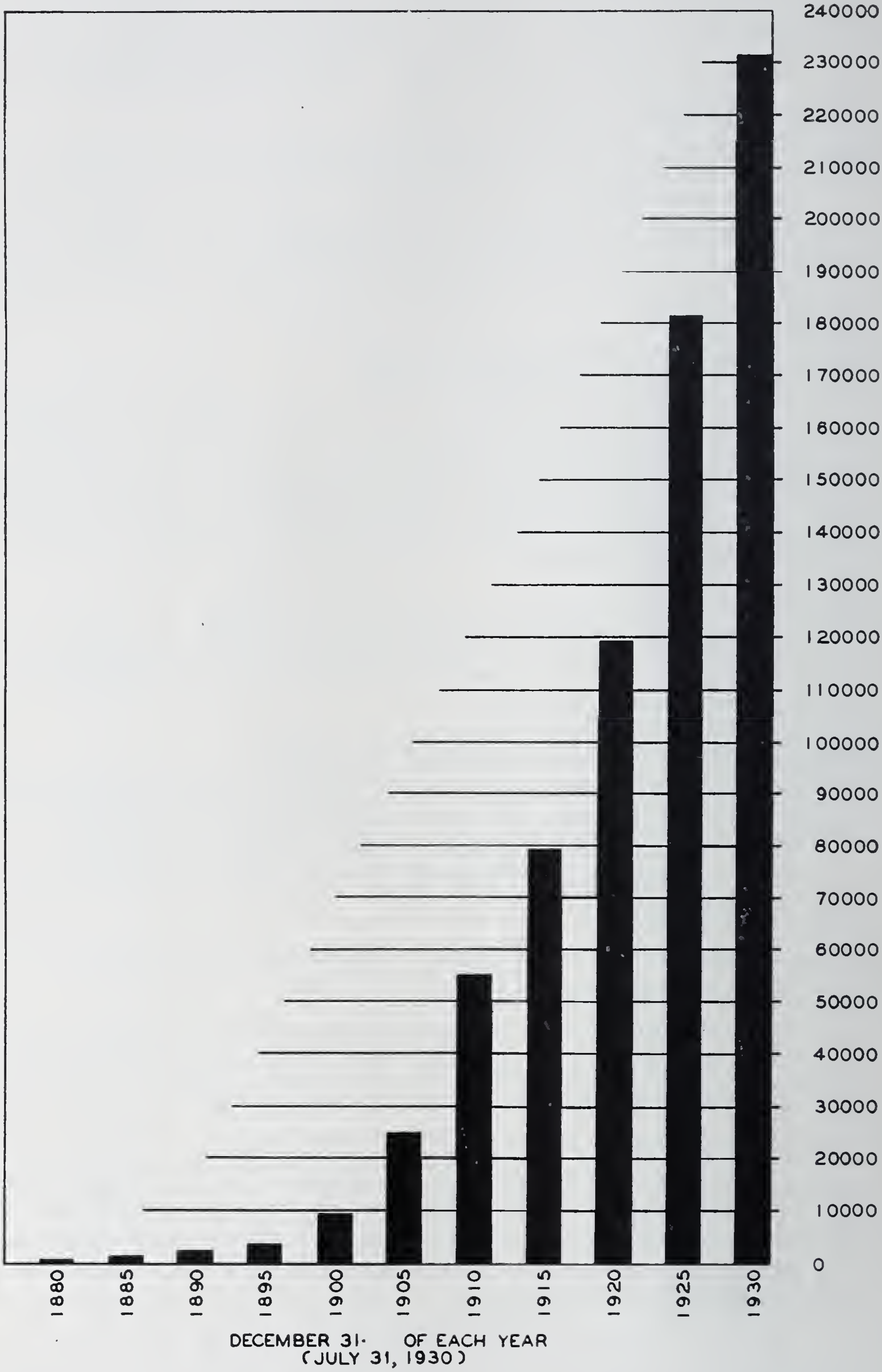


Fig. 1. Growth in Number of Telephones in Pittsburgh.

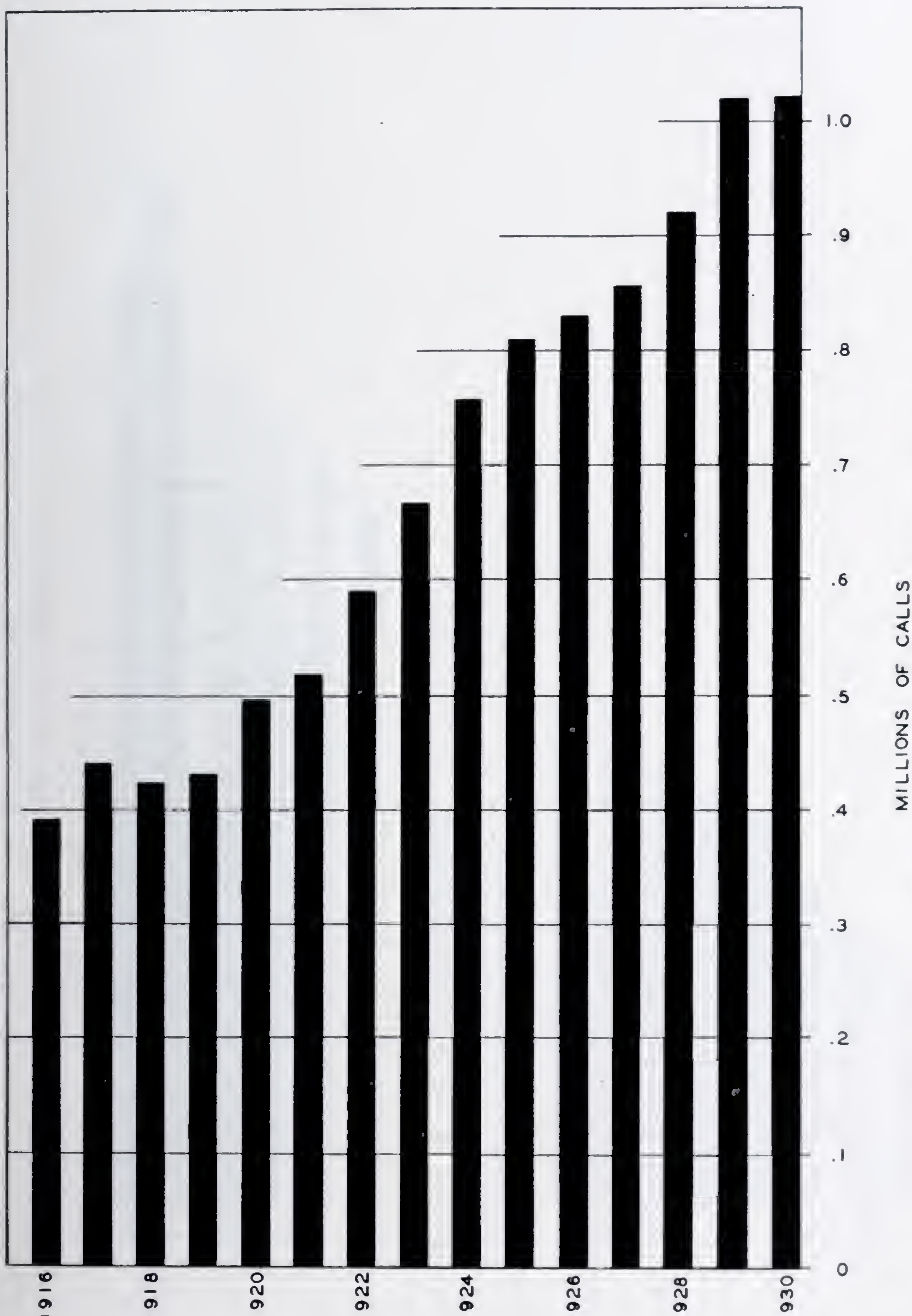


Fig. 2 Local Calls Daily in Pittsburgh.

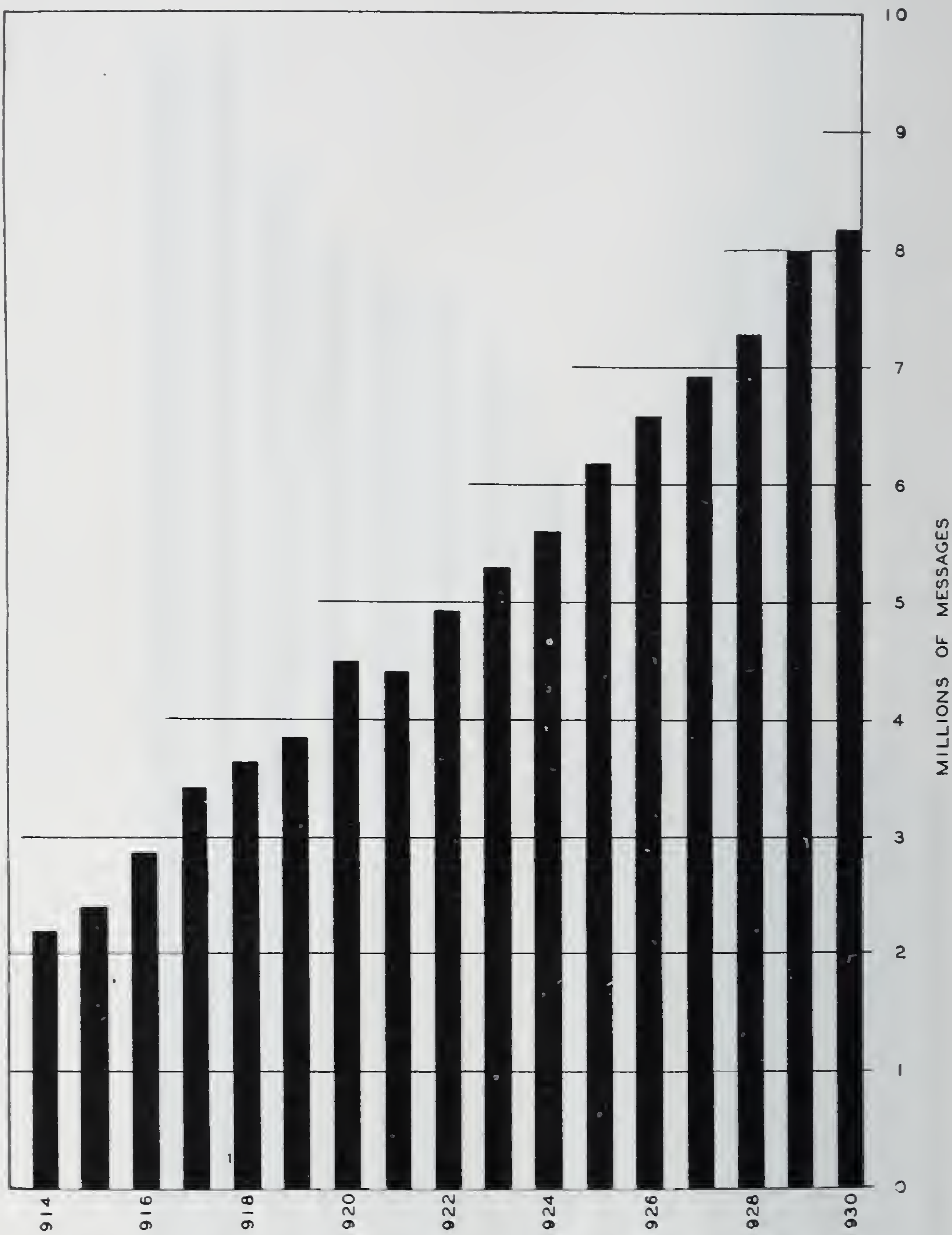


Fig. 3. Completed Toll Messages Annually in Pittsburgh.

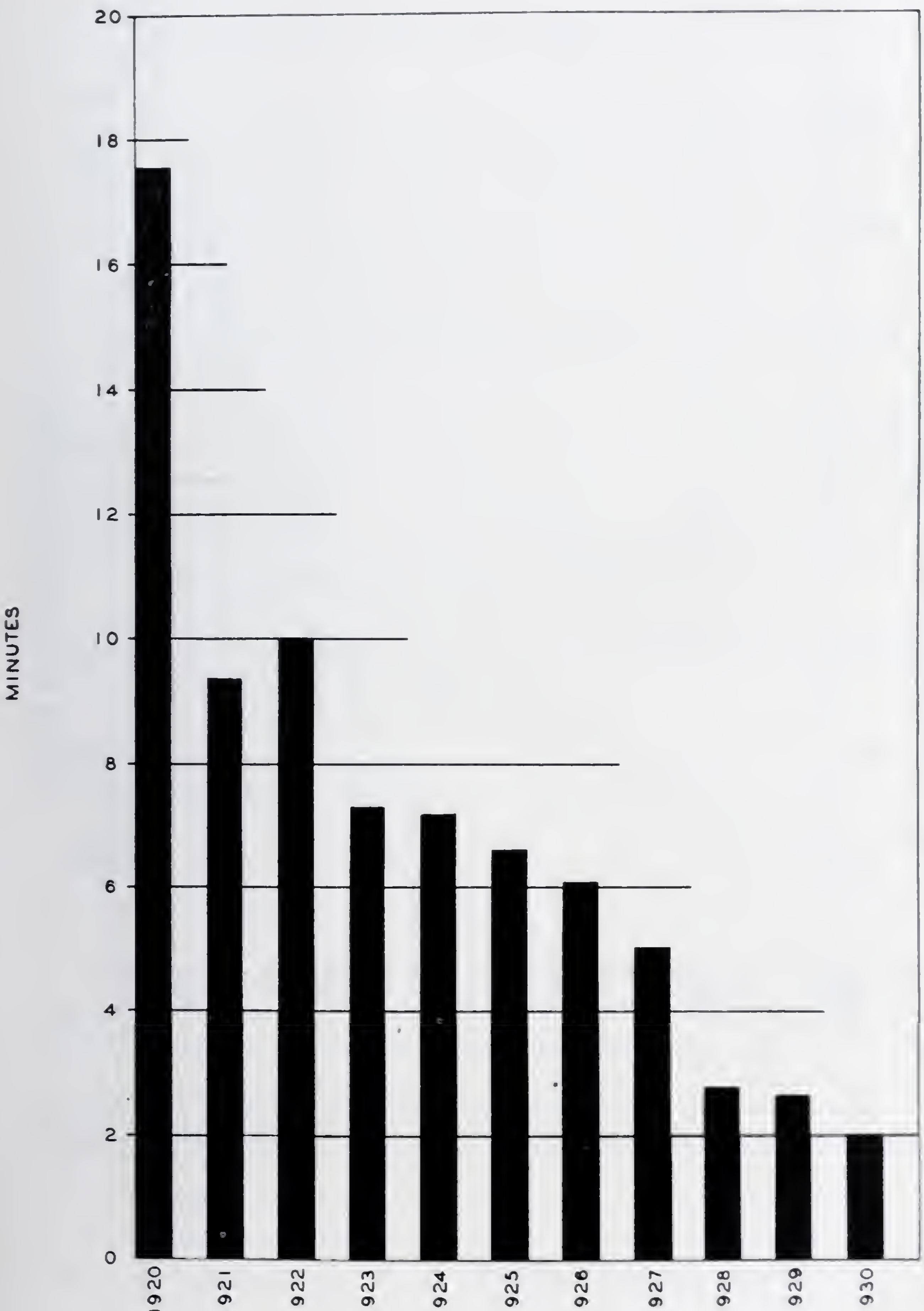


Fig. 4. Average Speed of Toll Service in Pittsburgh.

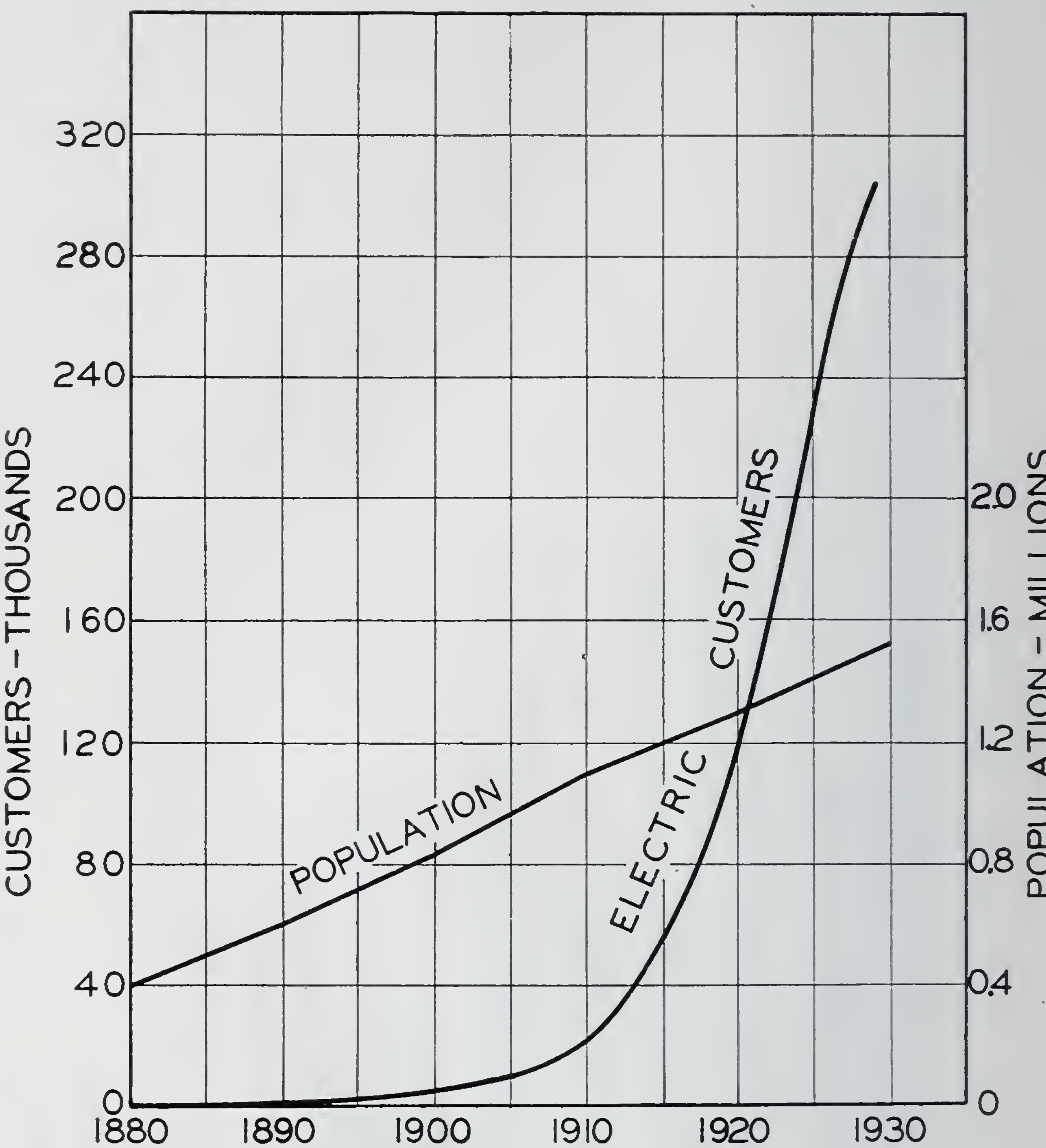


Fig. 5. Population and Number of Electric Customers in Pittsburgh District.

The Pittsburgh district includes Allegheny County and Beaver County. In this district the rate of increase in 10 years is as follows:

Population	17 per cent.
Customers	219 per cent.
Electrical energy supplied	165 per cent.

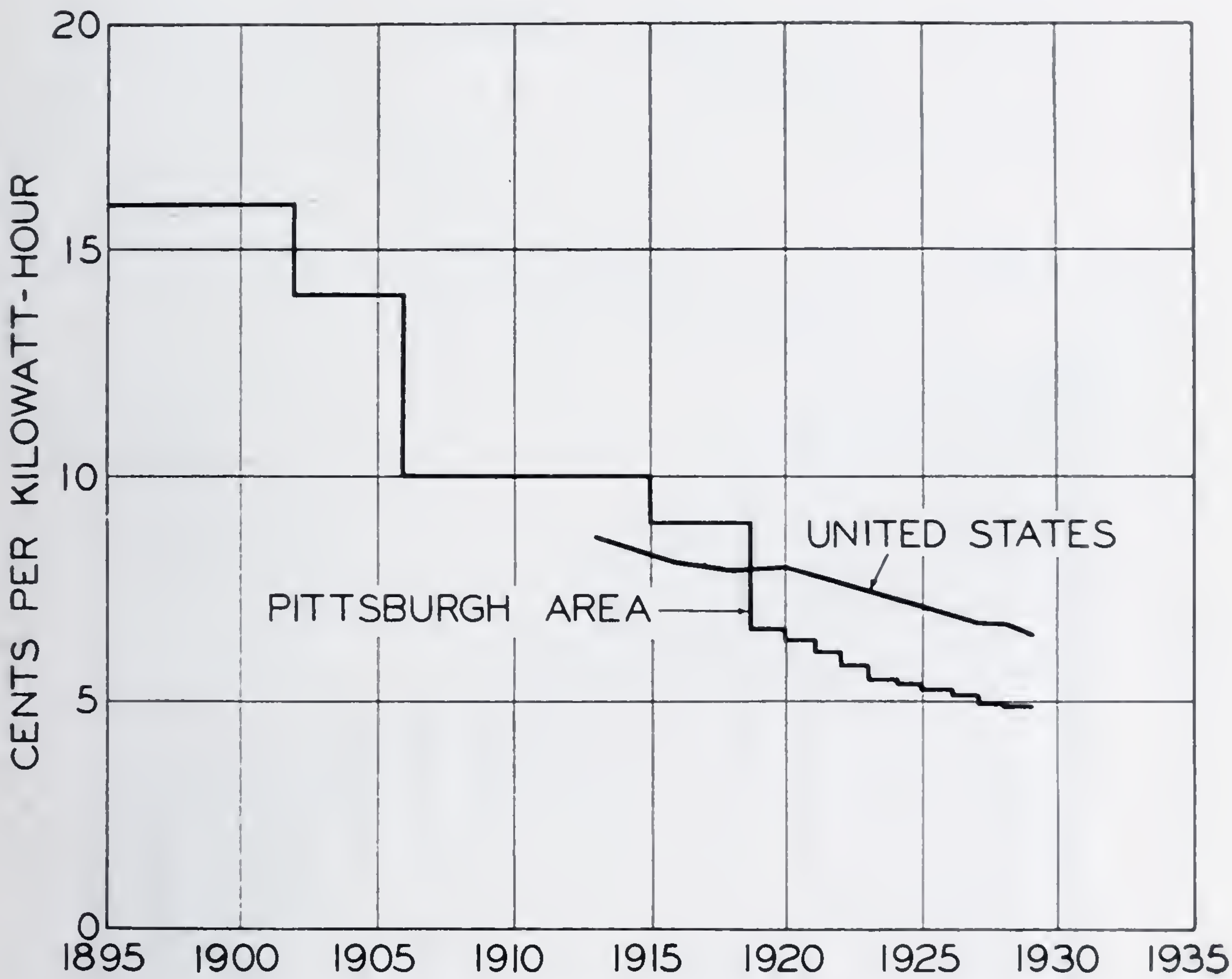


Fig. 6. Average Rate for Electricity Supplied to Domestic Customers.

In a period of rising prices in virtually all commodities, the average rate for electricity has shown a constant decrease. In the Pittsburgh area the cost, to the consumer, of electrical energy for domestic use has fallen from 16 cents per kilowatt-hour in 1895 to less than five cents per kilowatt-hour in 1929.

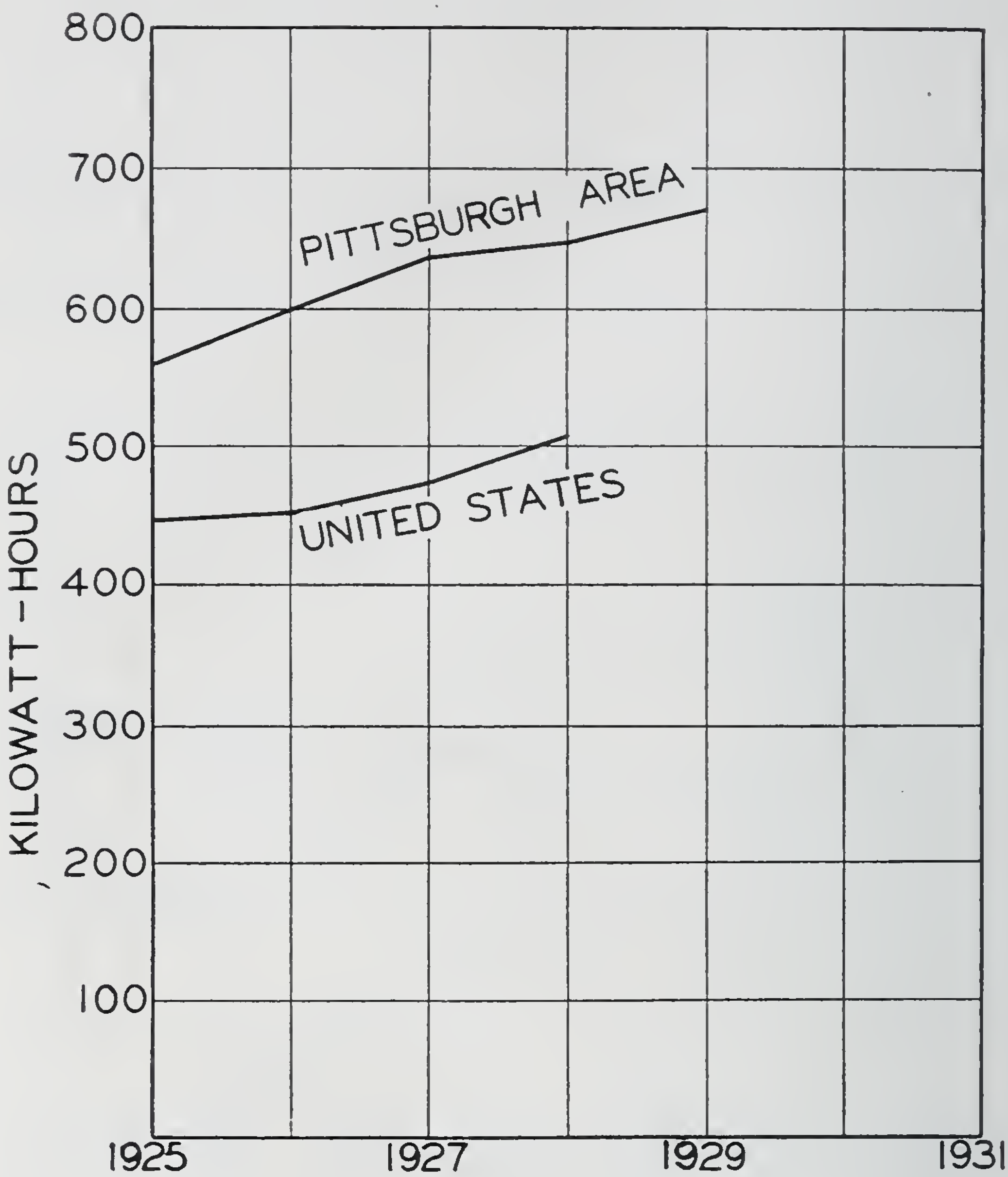


Fig. 7. Average Domestic Customer Use.

Each residence in the United States averages three or more electrical devices. Increased use has been stimulated by reduced rates for increased use ("inducement rates"), and by new devices, notably electric refrigerators.

The principal domestic uses of electricity, in addition to lighting, are for vacuum sweepers, washing machines, flat-irons, cooking ranges, refrigerators, toasters, percolators, waffle-irons, radios, fans, curling-irons, and heaters.

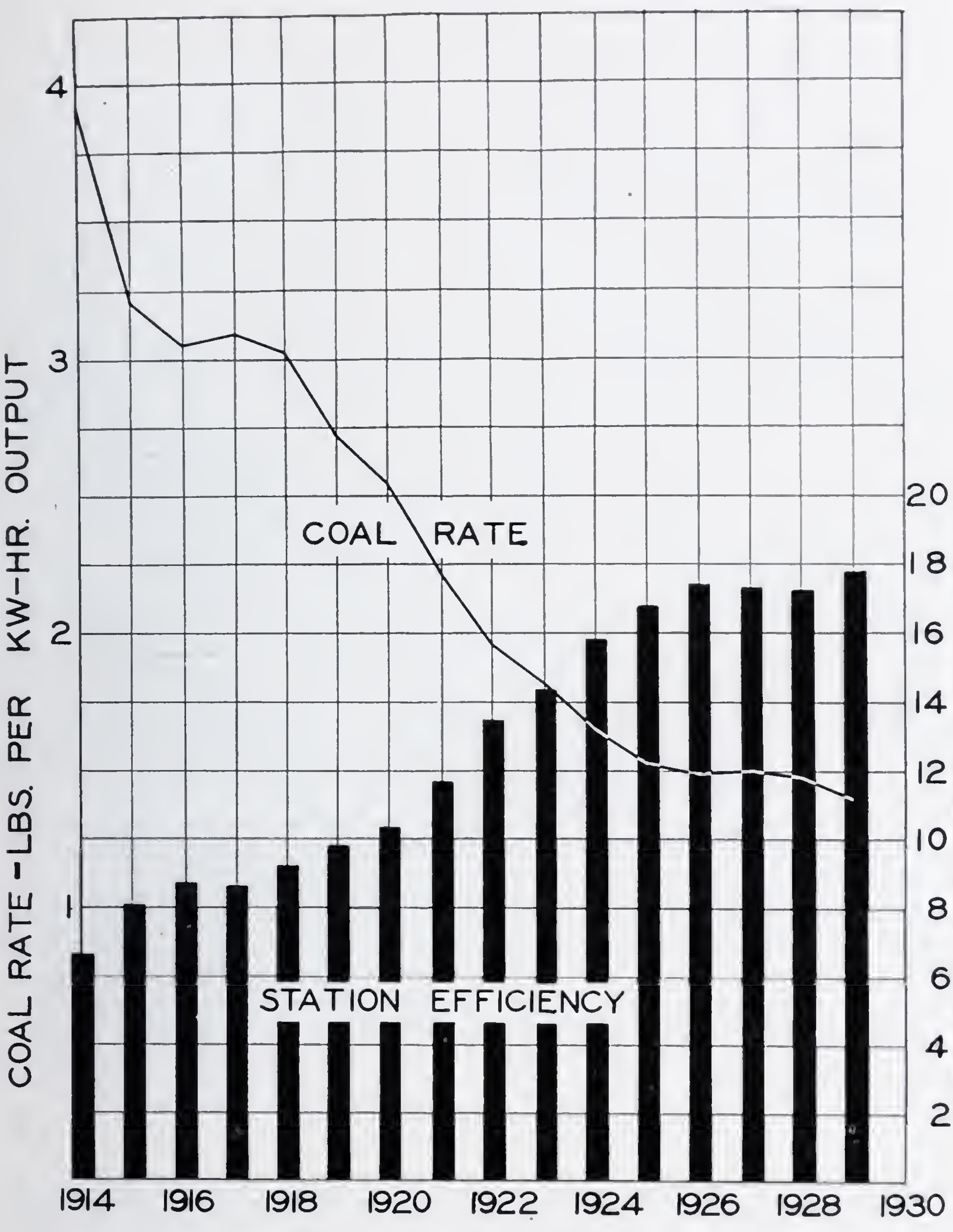


Fig. 8. Power-Plant Efficiency.

Engineering development in the production of electrical energy has brought about a vastly more efficient use of fuel, particularly in the past 15 years. The national coal rate in 1919 was 3.20 pounds per kilowatt-hour, and in 1928, 1.76 pounds per kilowatt-hour.

Duquesne Light Company operating conditions with low cost of coal do not justify increased cost of plant necessary for the higher efficiencies. In 1929, as compared with 1919, 31 per cent. more coal was produced, and 250 per cent. more electrical energy.

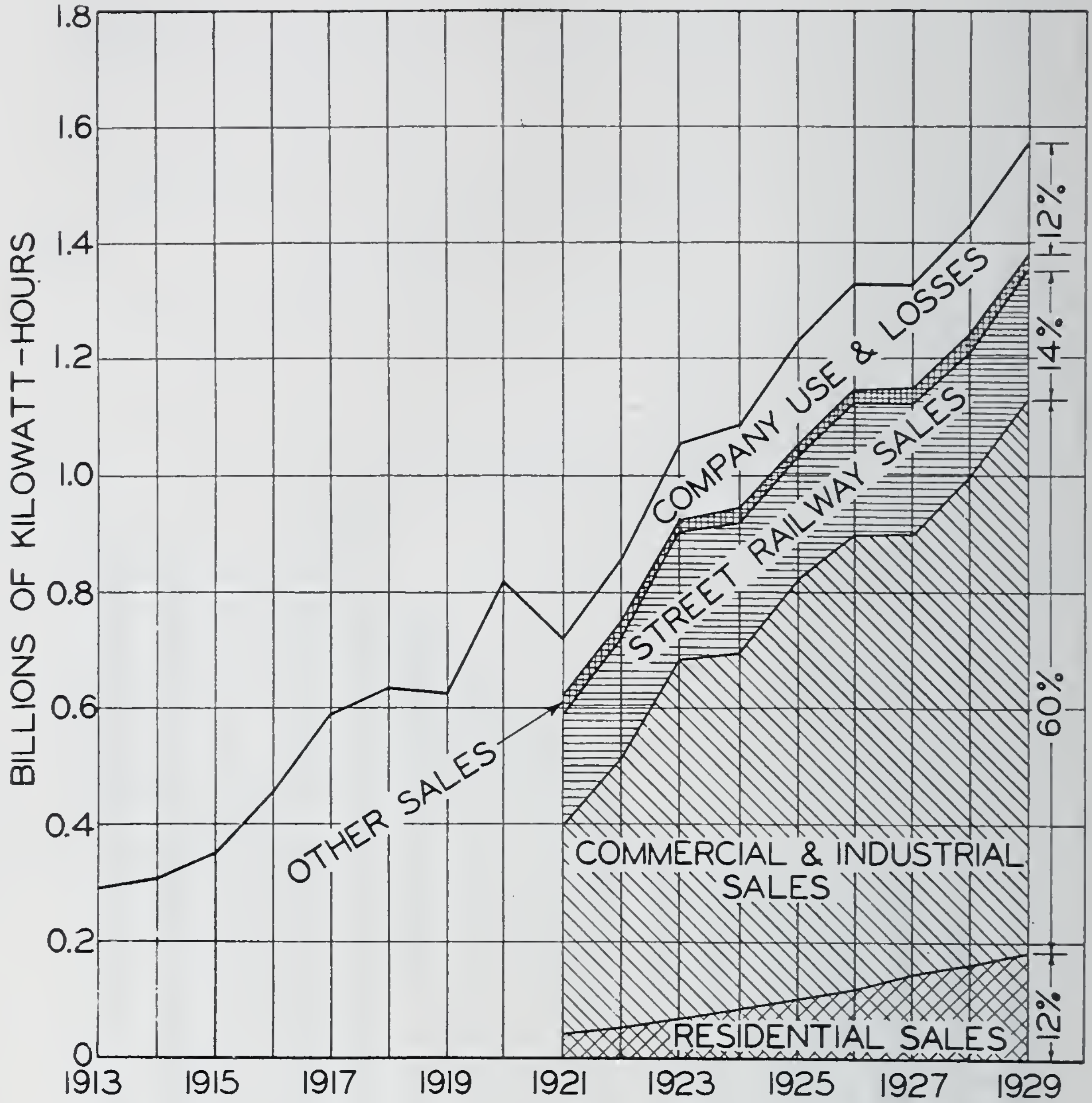


Fig. 9. Total Electric Energy Produced by Utility Companies in Pittsburgh District.

Pittsburgh area includes major portions of Allegheny and Beaver counties.

One-half of the total amount of sales is delivered at 11,000 and 22,000 volts.

The output of electrical energy has increased almost 4½ times in 14 years.

In eight years the commercial and industrial sales have increased 177 per cent., and the residential sales, 336 per cent.

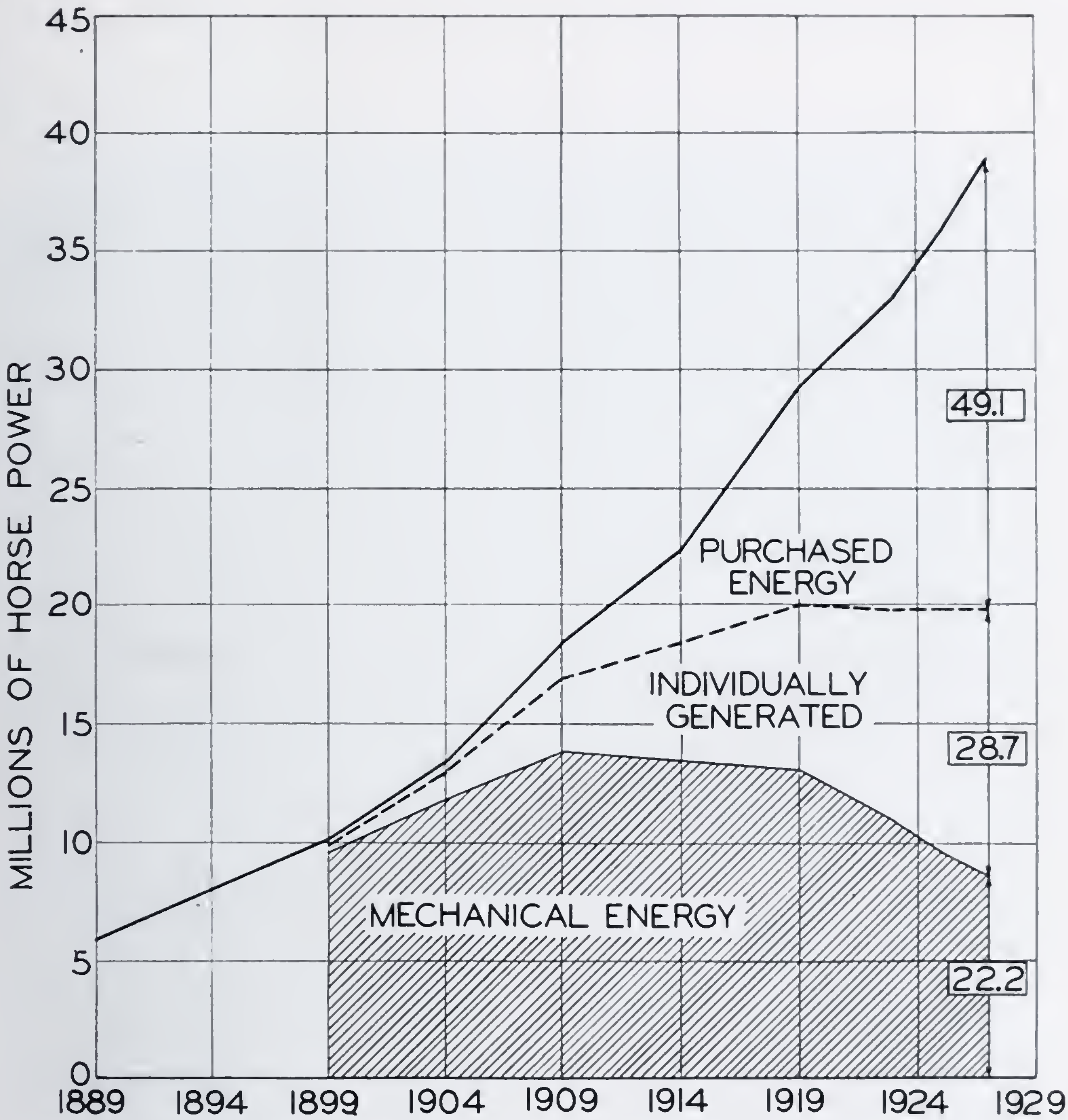


Fig. 10. Motorization of Industry.

The central stations have supplied a constantly increasing proportion of the total industrial horse-power in use. Thus, while in the past 10 years mechanical power has fallen off from 13,000,000 to 9,000,000 horse-power, central-station power has increased from 7,500,000 to 19,000,000 horse-power. In 1929, electrical horse-power was 77.8 per cent. of the total, while 49.1 per cent. was supplied from central stations. The mechanical power in industry is less than it was 30 years ago, although the total power is four times as great; that is, the electric power to-day is more than three times the total power 30 years ago.

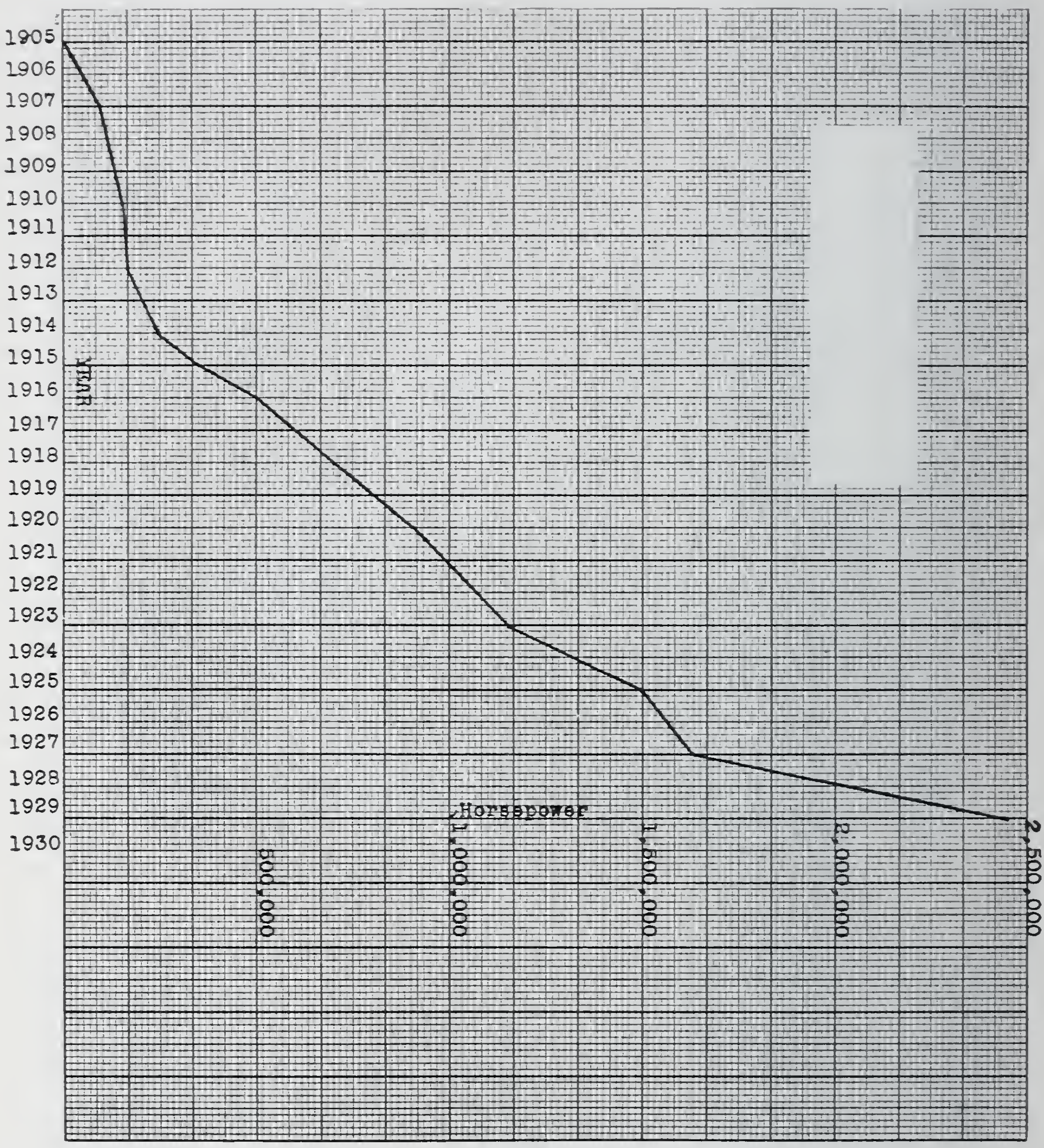


Fig. 11. Steel-Mill Electrification.

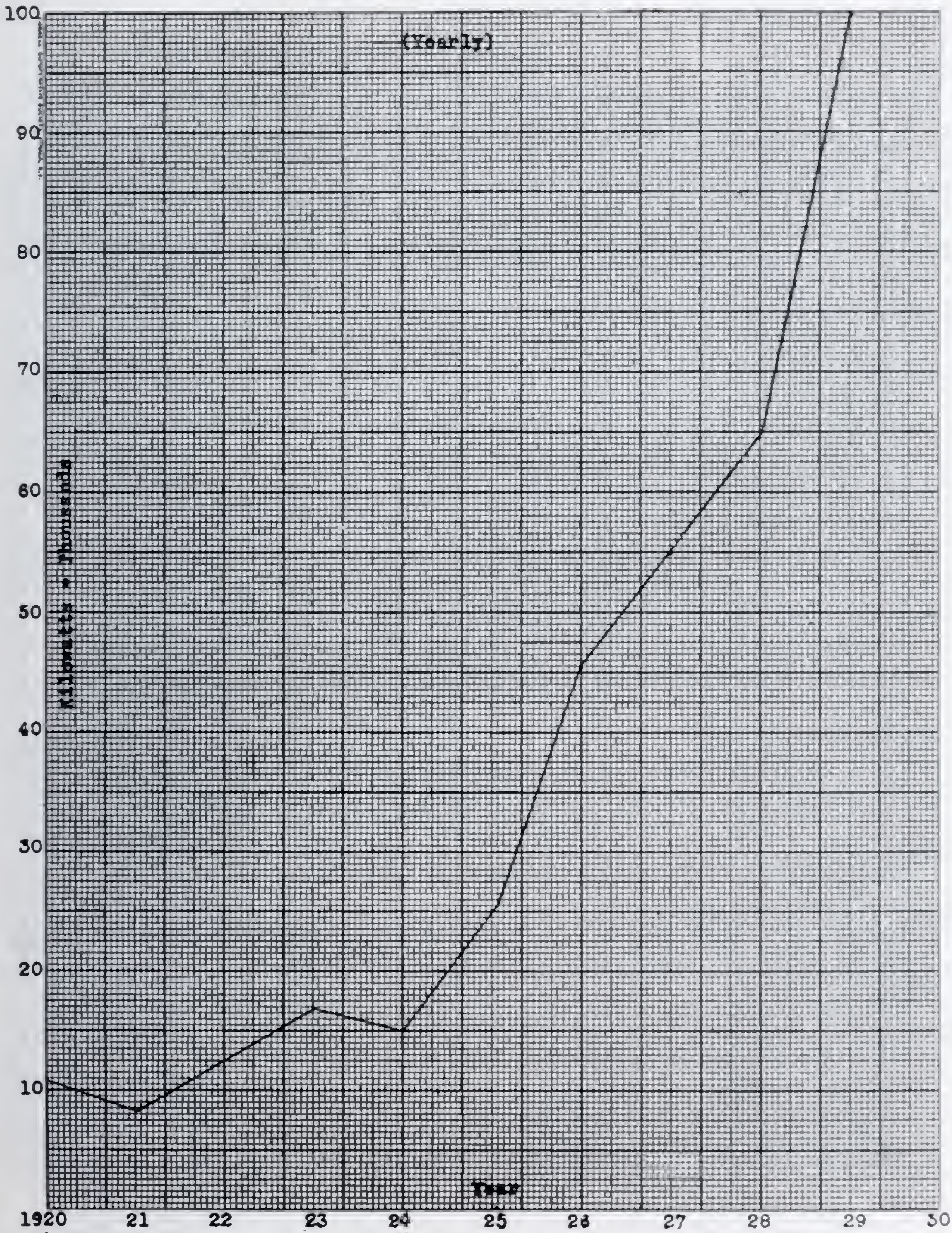


Fig. 12. Capacity of Electric Resistance Furnaces Sold by Nine Leading Companies.

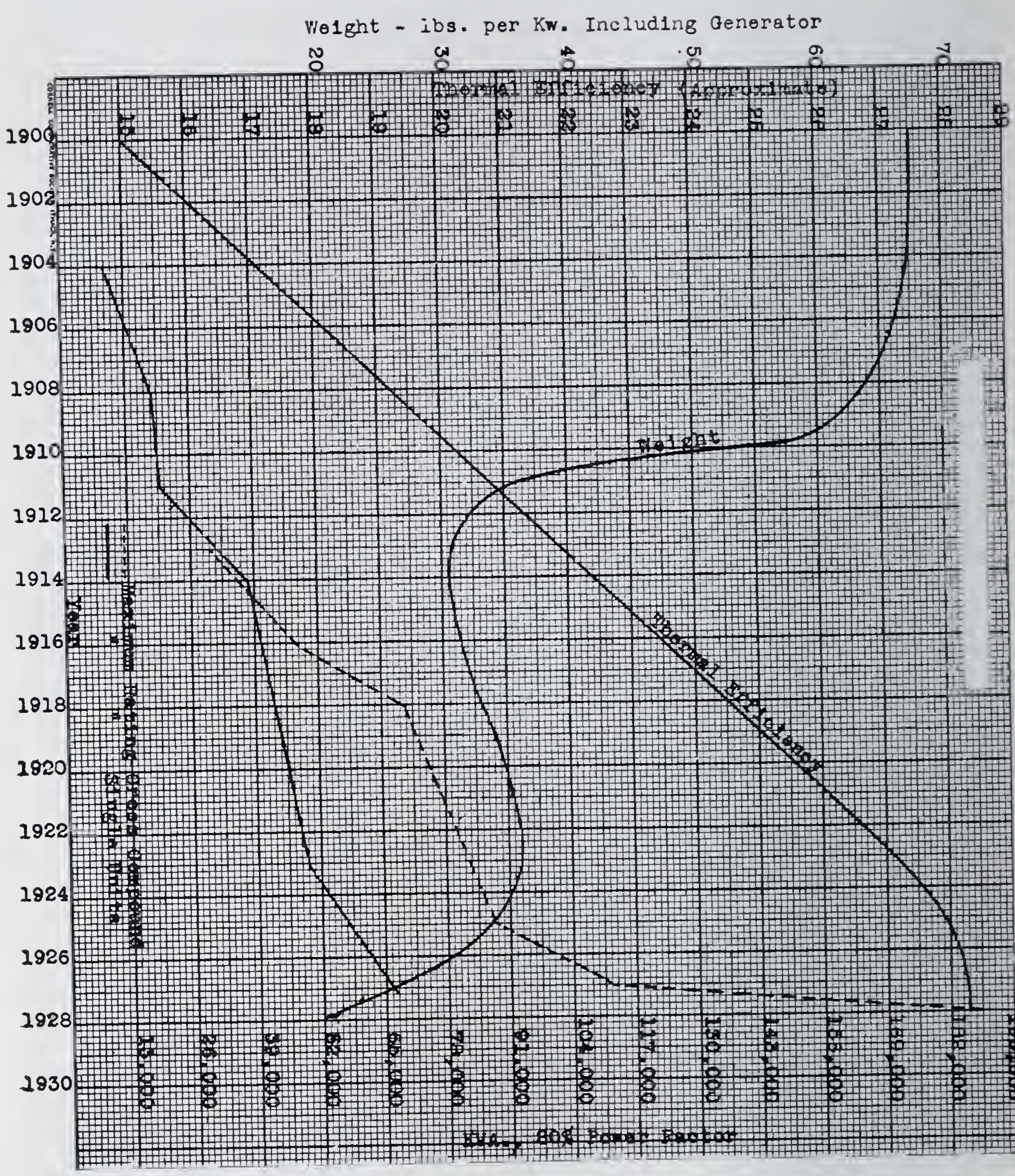


Fig. 13. Steam-Turbine Development.

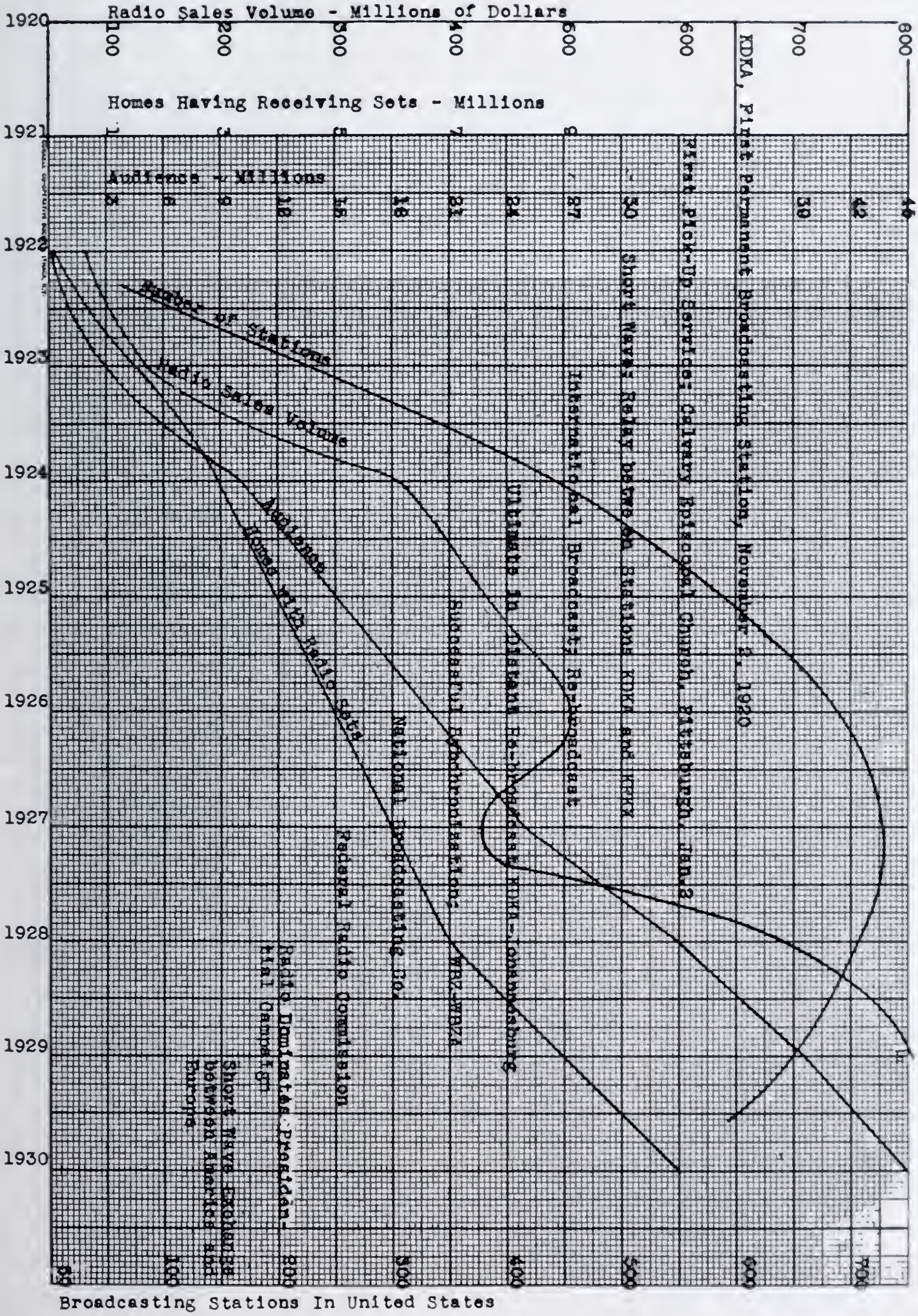
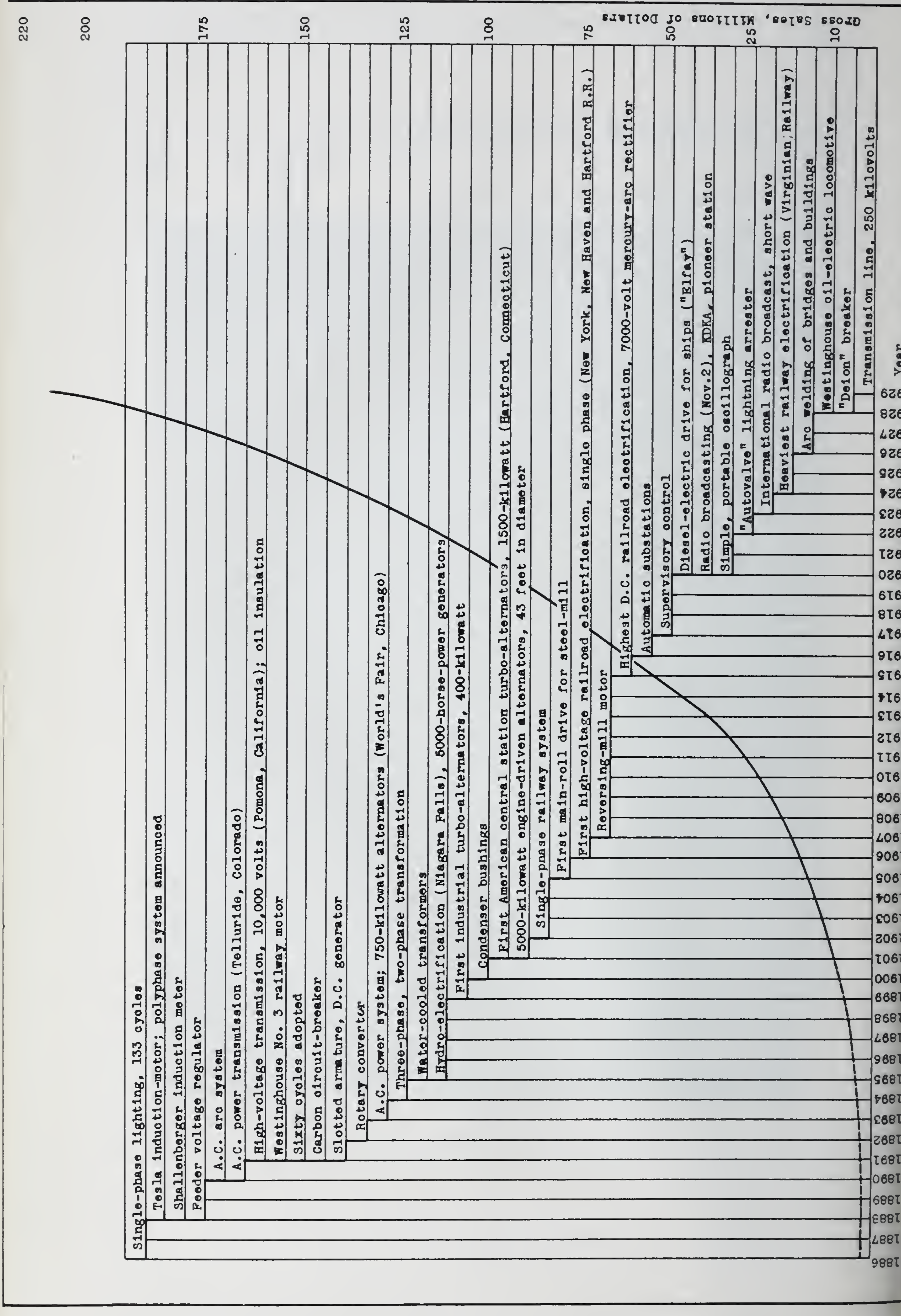


Fig. 14. Growth of Radio Industry.


Gross Sales, Millions of Dollars
220
200
175
150
125
100
75
50
25
10
Year
1886
1887
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1927
1928
1929
Single-phase lighting, 133 cycles
Tesla induction-motor; polyphase system announced
Shallenberger induction meter
Feeder voltage regulator
A.C. arc system
A.C. power transmission (Telluride, Colorado)
High-voltage transmission, 10,000 volts (Pomona, California); oil insulation
Westinghouse No. 3 railway motor
Sixty cycles adopted
Carbon circuit-breaker
Slotted armature, D.C. generator
Rotary converter
A.C. power system; 750-kilowatt alternators (World's Fair, Chicago)
Three-phase, two-phase transformation
Water-cooled transformers
Hydro-electrification (Niagara Falls), 5000-horse-power generators
First industrial turbo-alternators, 400-kilowatt
Condenser bushings
First American central station turbo-alternators, 1500-kilowatt (Hartford, Connecticut)
5000-kilowatt engine-driven alternators, 43 feet in diameter
Single-phase railway system
First main-roll drive for steel-mill
First high-voltage railroad electrification, single phase (New York, New Haven and Hartford R.R.)
Reversing-mill motor
Highest D.C. railroad electrification, 7000-volt mercury-arc rectifier
Automatic substations
Supervisory control
Diesel-electric drive for ships ("Elfay")
Radio broadcasting (Nov.2), KDKA, pioneer station
Simple, portable oscillograph
"Autovalve" lightning arrester
International radio broadcast, short wave
Heaviest railway electrification (Virginian Railway)
Arc welding of bridges and buildings
Westinghouse oil-electric locomotive
"Deion" breaker
Transmission line, 250 kilovolts

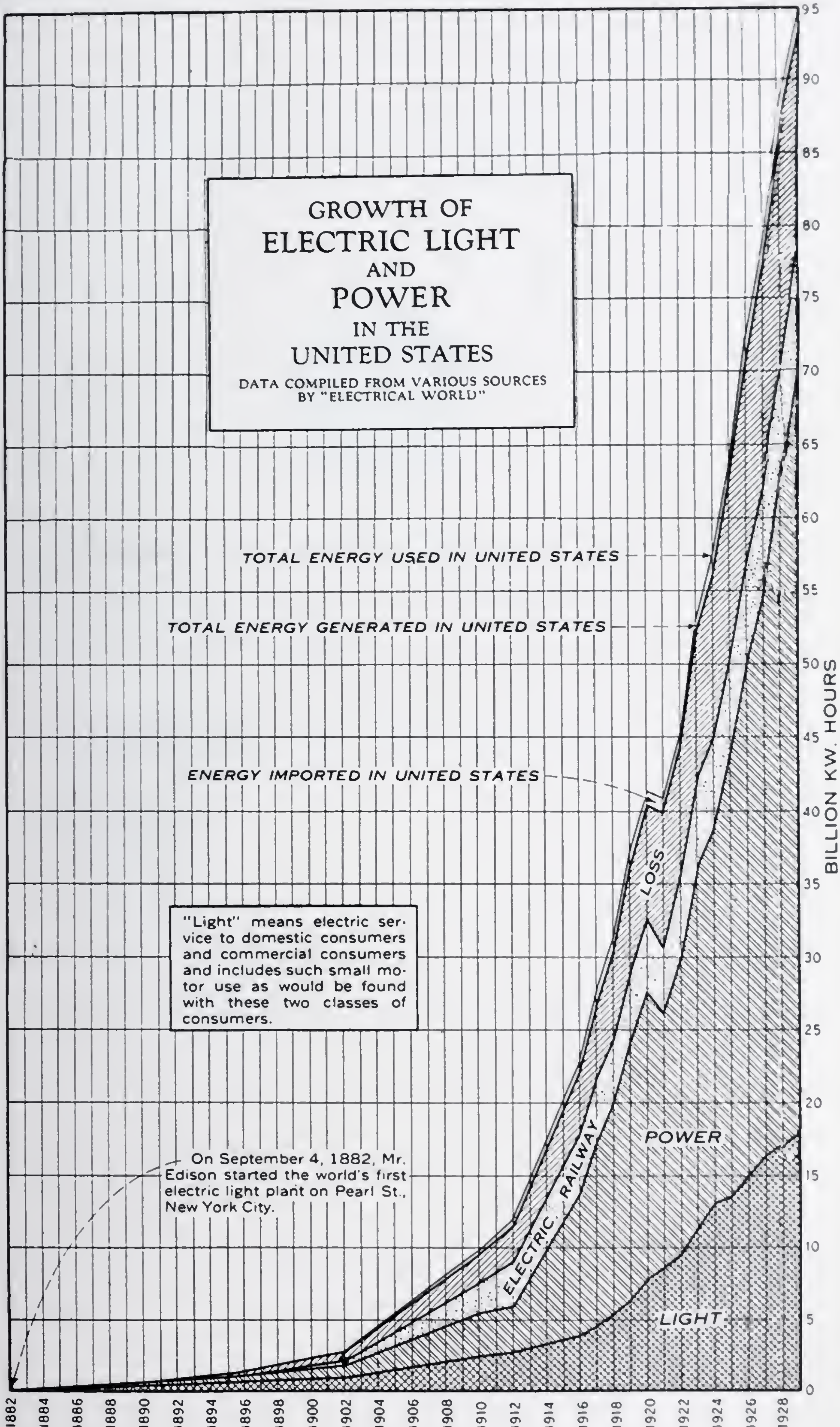

Fig. 16. Growth of Electric Light and Power.

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of

Western Pennsylvania

Incorporated 1880

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Corrected to Jan. 1st, 1931

William Penn Hotel
Pittsburgh, Pa.

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Incorporated 1880

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RULES GOVERNING THE AWARD OF MEDALS

The Board of Direction on May 11, 1907 authorized the award, each year, of two medals gold and silver, to Members of the Society under the following rules, which were revised May 28, 1915 and December 15, 1925.

---

1. There will be two medals, one of gold and the other of silver.

2. The awards are to be made by the Board of Direction on the recommendation of a committee of three, appointed by the President, from its members.

3. Medals shall be open for competition to all authors of papers. No person shall receive both medals in any one year. In case of award to a paper of joint authorship, separate medals shall be given to each author.

4. The medals shall be awarded to the authors of the best and second best papers presented during the year.
   The value of the papers shall be judged on the following points:
   (a) Value to engineering profession.
   (b) Originality of subject matter.
   (c) Treatment.

5. The Directors may refuse to grant either or both medals in any one year when no paper deemed worthy of award is presented.

6. Papers presented at regular meetings of the Society or its Sections and which are printed in the Proceedings only are eligible for award.

7. The medals shall be presented at some meeting of the General Society, subsequent to the annual meeting.

8. The recipient's name and the year of award shall be engraved on each medal, and suitable designation of Medalist shall be made annually in the published List of Members and their names enrolled on a roll of honor displayed in the Society Rooms.

Engineers' Society of Western Pennsylvania

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And the Year in which They Held Office

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*Barnes, Phineas		'90 '91 '92			
*Barbour, George H					'13 '17 '18 '19
*Barnsley, Geo. T.	1909	'07 '08			'05 '06
*Becker, Max J.	1893	'87			'89 '90
Berg, P. T.					'99 '00
*Bole, W. A.	1900	'98 '99			'96 '97
*Brashear, John A	1889	'87 '88			
Brown, Geo. H	1885				
Butz, E. M.					'80
*Camp, J. M.	1904	'03			'97 '98 '01 '02
*Carhart, Daniel			'94 '95 '96		
Chester, J. N.	1929	'27 '28			'09 '10 '11
*Clark, R. N.			'92 '93		'90 '91
Clifford, T. C.					'25 '26 '27
Connelley, C. B					'01 '02 '03
Covell, V. R.					'27 '28 '29
*Crabtree, Frederic	1924	'22 '23			'14 '15 '16
Craver, Harrison W					'08 '09 '10
Cummings, Robt. A					'07 '08 '09
Danforth, George H	1921	'19 '20			'16 '17 '18
Davison, Allen S		'31			'28 '29 '30
Davison, Geo. S.	1898	'96 '97			'91 '92
*Davis, Chas.	1894	'92 '93			'88 '89
*Dempster, A	1887–8	'86			'82 '83 '84
Diehl, A. N.					'18
*Diescher, Samuel	1905	'03 '04			'81 '82
Duff, Samuel E.	1916	'14 '15			'11 '12 '13
Eavenson, Howard N					'26 '27 '28
Edgar, L. C	1931	'29 '30			'26 '27 '28
*Ellis, Frank I.					'23 '24 '25
*Engstrom, Frans					'96 '97
*Ferris, G. W. G					'92 '93
Fessenden, R. A			'97 '98 '99 '00		
Fieldner, A. C					'27 '28 '29
*Fisher, S. B.		'86			'84 '85
Fisher, H. W.	1901	'99 '00			
Flanagan, Gerald E.		'04 '05			
Fohl, W. E.	1926	'24 '25			'20 '21 '22
*Frost, A. E				1881–1917	
Goodspeed, G. M					'24 '25 '26
Grace, S. P.	1913	'11 '12			'08 '09 '10
*Gottlieb, A.	1882–3	'80 '81			
Handy, James O	1912	'10 '11			'07 '08 '09
*Harlow, J. H.			'80 to '84 '91		
Haslam, E. H					'13 '14 '15
*Hildner, L. F. W					'21 '22
Hawley, W. C.	1920	'18 '19			'12 '13 '14
Hiles, Elmer K			1908 to 1917		
*Hirsh, Richard			'08		'01 '02
Hobbs, J. C					'22 '23 '24
*Hoerr, A. L.	1917	'15 '16			'12 '13 '14
*Hoopes, Wm.					'15 '16
*Hunt, A. E.	1892	'89 '90 '91			'87 '88
Hunter, John A.	1928	'26 '27			'20 '21 '22
*Hyde, Charles					'02 '03
James, H. D.	1922	'20 '21			'16 '17 '18
*Johnson, T. H.	1895	'93 '94			'91 '92
*Kaufman, Gustave					'99 '00
Kennedy, Julian	1906				'94 '95
*Kent, William				'80	
Khuen, Richard, Jr					'22 '23 '24

*Deceased.

Tabular list of Past and Present Officers

NAME	President	Vice President	Secretary	Treasurer	Director
KINTNER, S. M.	1907	'05 '06			'03 '04
KNOWLES, MORRIS	1923	'21 '22			'05 '06
*KOCH, WALTER E.					'93 '94
LABOON, J. F.					'30 '31
LADD, GEORGE T.	1927	'25 '26			'21 '22 '23
LELAND, E. D.					'23 '24 '25
LESHER, C. E.					'29 '30 '31
LEWIS, H. J.	1899	'97 '98			'95 '96
LINTON, ROBERT					'16 '17 '18
*LIVINGSTON, MAX					'83
*LOWRY, J. L.					'80 '81
LYONS, J. K.	1908	'06 '07			'04 '05
McCLINTIC, H. H.					'97 '98
McDOWELL, N. M.					'80 '81
McLOUGHLIN, T. J.					'28 '29 '30
McMULLIN, F. V.			'05 '06		
*MARTIN, WILLIAM					'85 '86
*METCALFE, WILLIAM	1880–1				'84 '85 '89 '90
*MILLER, WILLIAM	1884				'83
MINTON, J. H.					'20
MORSE, E. K.	1910	'08 '09			'06 '07
MOTT, W. E.					'12 '16 '17 '18
*MUNROE, ROBERT					'82 '83
NEILSON, GEORGE H.	1919	'17 '18			'14 '15 '16
OSLER, GEORGE F.					'31
*PHILLIPS, F. C.		'83 '84 '85 '01 '02			'81 '82 '86 '87 '99 '00
PHILLIPS, F. R.		'30 '31			
PITTMAN, E. W.					'17 '18 '19
RAYMER, A. R.	1914	'13			'06'07'10'11'12
RIDDLE, WALTHER	1911	'09 '10			'07 '08
RIDINGER, C. W.			'01 '02 '03 '04		
*ROBERTS, T. P.	1891				'88 '89 '94 '95
*RODD, THOMAS		'81 to '84			'80
*SCAIFE, W. L.	1890	'88 '89			'86 '87
SCHATZ, FRED C.					'19 '20 '21
SCHAUER, F. F.					'30 '31
*SCHELLENBERG, F. C.					'07 '08 '09
SCOTT, CHARLES F.	1902	'00 '01			'98 '99
SCOTT, GUSTAVE					'98
SKINKLE, W. B.					'29 '30 '31
SMITH, M. V.					'82
*SNYDER, W. E.	1918	'16 '17			'13 '14 '15
SPELLER, F. N.					'20
SPELLMIRE, WALTER B.	1925	'23 '24			'19 '20 '21
STAHL, K. F.					'95 '96
STOLTZ, G. E.					'31
STROBEL, C. L.		'85 '86			
STUCKI, A.	1915	'13 '14		1917 to date	'11 '12
*SWENSSON, EMIL	1897	'95 '96			'93 '94
*TAYLOR, E. B.	1886				'87 '88
TAYLOR, S. A.	1913	'12			'09 '10 '11
*TAYLOR, SELWYN M.					'03
TERRY, C. D.					'22
*THAW, WILLIAM, JR.		'82			'85 '88
TRESCHOW, K. F.			1917 to date		
UNGER, JOHN S.					'15 '16
WELDIN, W. A.					'24 '25 '26
WHITED, WILLIS					'04 '05 '10 '11
*WICKERSHAM, S. M.			'86 '90		
*WILKINS, W. G.	1896	'94 '95			'90 '91
WILLIAMS, J. I.		'80			
WILSON, H. D.					'19
WORTHINGTON, CHARLES					'04
*YARDLEY, EDMUND				'07	
ZIMMERMAN, W. F.			'85		

*Deceased.

GENERAL INFORMATION

Meetings: Regular meetings of the Society are held on the third Tuesday of each month, except July and August.

Civil Section Meetings: First Tuesday in January, March, May, September and November.

Electrical Section Meetings: Second Tuesday each month except June, July and August.

Illuminating Engineers' Section: Bi-Monthly, January, March, May, September and November.

Mechanical Section Meetings: First Tuesday in February, April, June, October and December.

Mineral Industries Section Meetings: Fourth Tuesday in January, March, May, September and November.

Practising Engineers' Section Meetings: Third Wednesday of February, April, June, October and December.

Steel Works Section Meetings: Fourth Tuesday in February, April, June, October and December.

Annual Meeting of the Society: Third Tuesday in January.

The Society rooms and Library are open every day, except Sundays, Memorial Day, Fourth of July, Labor Day, Thanksgiving, Christmas and New Years from 8:30 A. M. to 10:30 P. M.

Publications: The Society issues a publication, Proceedings, ten months in the year, containing the original papers on technical subjects read before the Society, together with all discussion offered in connection therewith; minutes, reports, engineering data and other matters of record. The Proceedings are furnished to the entire membership.

Reprints from this publication, which is copyrighted, may be made by any other publication on condition that the full title of paper, name of author, page reference, and date of presentation to the Society are given. This does not apply to matter under Engineering Data, republication of which is reserved to the Society.

No paper read before the Society shall be published in any magazine or journal before its appearance in the Proceedings, and no paper previously published shall be published in the Proceedings without the sanction of the Board.

The annual subscription to the Proceedings is $5.00. Single copies 50c each.

A List of Members of the Society is published annually.

Professional Papers: All persons, whether members of the Society or not, are invited to send in papers and discussions on engineering subjects. All papers and discussions are under the supervision of the Publication Committee and are subject to proper editing.

Admission to Membership: The membership of the Society consists of Honorary Members, Members, Associate Members, Associates, Juniors and Student Juniors. The qualifications for membership are given in Article I of the By-Laws.

The Entrance Fee for Members, Associate Members and Associates is $10.00; Juniors and Student Juniors are not required to pay this fee. The annual dues for Resident Members, Associate Members and Associates are $20.00, Resident Juniors $10.00, and Resident Student Juniors $3.00; for Non-resident Members, Associate Members and Associates $10.00, for Non-resident Juniors $7.50, and for Non-resident Student Juniors $3.00. Payment of dues for the unexpired quarters of the year only is required on entrance to the Society.

Society Pins: The Society Emblem, a small reproduction of the Seal of the Society, in blue enamel mounted in solid gold, may be obtained in either the pin or button style and will be mailed on receipt of $3.00 covering cost.

Exchange of House Privileges: House and Library privileges are exchanged, on presentation of membership cards, with the following Engineering Societies:

American Society of Civil Engineers, New York.
American Society of Mechanical Engineers, New York.
American Institute of Electrical Engineers, New York.
American Institute of Mining & Metallurgical Engineers, New York.
Boston Society of Civil Engineers, Boston, Mass.
Brooklyn Engineers' Club, Brooklyn, New York.
Engineering Society of Buffalo, Buffalo, N. Y.
Civil Engineers' Society of St. Paul, St. Paul, Minn.
Cleveland Engineering Society, Cleveland, Ohio.
Detroit Engineering Society, Detroit, Mich.
Engineers' and Architects' Club, Louisville, Ky.
Engineering Institute of Canada, Montreal, Canada.
Engineers' Club of Baltimore, Baltimore, Md.
Engineers' Club of Dayton, Dayton, O.
Engineers' Club of Kansas City, Kansas City, Mo.
Engineers' Club of Minneapolis, Minneapolis, Minn.
Engineers' Club of Philadelphia, Philadelphia, Pa.
Engineers' Club of St. Louis, St. Louis, Mo.
Engineers' Club of Seattle, Seattle, Wash.
Engineers' Club of Toronto, Toronto, Canada.
Engineers' Society of Pennsylvania, Harrisburg, Pa.
Louisiana Engineering Society, New Orleans, La.
Rochester Engineering Society, Rochester, N. Y.
Society of American Military Engineers, Washington, D. C.
Technology Club of Syracuse, Syracuse, N. Y.
Technical Society of the Pacific Coast, San Francisco, Cal.
Toledo Society of Engineers, Toledo, O.
Western Society of Engineers, Chicago, Ill.

MEDAL AWARDS FOR PAPERS

1907

HENRY SEWALD PRICHARD

GOLD MEDAL

"PROPORTIONING OF STEEL RAILWAY BRIDGE MEMBERS"

THOMAS PASCHAL ROBERTS

SILVER MEDAL

"FLOODS AND MEANS OF THEIR PREVENTION IN OUR WESTERN RIVERS"

1912

FREDERICK G. GASCHE

SILVER MEDAL

"THEORY OF STEAM ACCUMULATORS AND REGENERATIVE PROCESSES"

1915

ARTHUR W. THOMPSON

GOLD MEDAL

"MAGNOLIA CUT-OFF IMPROVEMENT ON THE BALTIMORE & OHIO RAILROAD"

BENJAMIN FELAND GROAT

SILVER MEDAL

"PITOT TUBE FORMULAS—FACTS AND FALLACIES"

1916

JOHN A. HUNTER

SILVER MEDAL

"TESTS ON A RECENT TYPE OF CHAIN GRATE STOKER AND NEW METHODS OF BAFFLING STIRLING BOILERS"

1917

A. L. HUMPHREY

GOLD MEDAL

"MOBILIZATION OF MATERIAL AND INDUSTRIAL RESOURCES"

ROBERT LINTON

SILVER MEDAL

"THE WINDOW GLASS MACHINE"

1918

JAMES STEWART MARTIN

SILVER MEDAL

"NEW AND LITTLE KNOWN METHODS OF THE CALCULATION OF BEAMS, GIRDERS, AND ARCHES"

1919

ARTHUR E. CROCKETT

SILVER MEDAL

"CAST STEEL ANCHOR CHAIN"

1920

MORRIS KNOWLES and MAURICE R. SCHARFF

SILVER MEDALS

Joint Paper

"REGIONAL PLANNING IN THE PITTSBURGH DISTRICT"

1921

J. BRADLEY MANDEVILLE

SILVER MEDAL

"AERIAL PHOTOGRAPHY AS APPLIED TO SURVEYING."

1922

JAMES STEWART MARTIN

SILVER MEDAL

"STRUCTURAL ENGINEERING PROBLEMS IN TRANSMISSION —LINE CONSTRUCTION"

1923

J. C. HOBBS and L. W. HELLER

SILVER MEDALS

Joint Paper

"PULVERIZED FUEL FOR LARGE BOILERS"

1924

E. K. MORSE

SILVER MEDAL

"SOLUTION OF THE TRANSPORTATION, PARKING, AND FLOOD PROBLEMS OF PITTSBURGH".

LIFE MEMBERS

GEORGE H. DANFORTH

GEORGE S. DAVISON

WILLIAM E. FOHL

L. C. FROHRIEB

HENRY D. JAMES

GEORGE T. LADD

HARRY J. LEWIS

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ARNOLD STUCKI

SAMUEL A. TAYLOR

LIST OF MEMBERS

ALPHABETICAL LIST OF MEMBERS OF ALL GRADES

*A star placed before the name of a member indicates that he has contributed one or more papers to the Society's Proceedings.

Ackenheil, Alfred C. (Jan. 1908; Feb. 1925) Engineer, John F. Casey Co, P. O. Box 1753; h, 3102 Landis St, Pittsburgh, Pa. . . . **Sterling 1400**

Acker, Albert J. (March 1925) Sales Engr, Manning, Maxwell & Moore, Inc, 1411 Park Bldg; h, 427 Forest Ave, Bellevue, Pittsburgh, Pa. . . . . **Atlantic 6330**

Adair, William R. (Associate) (Dec. 1924) Supt, Pittsburgh, Mars & Butler Rwy Co, Mars, Pa; h, Mars, Pa. . . . . **Mars 28-R-3**

Adams, Henry Clay (Oct. 1922) 5304 St. James Terrace, Pittsburgh, Pa.

AFFELDER, WILLIAM L. (Past President 1930) (Oct. 1913) Vice Pres, Hillman Coal & Coke Co, 2306 First National Bank Bldg; h, 12 Dinsmore Ave, Crafton, Pittsburgh, Pa. . . . . **Atlantic 2620**

Agthe, Fred Thomas (June 1924) Sales Engr, Allis-Chalmers Mfg. Co, Milwaukee, Wis; h, 1400 Wisconsin Ave, Milwaukee, Wis.

Alexander, J. Irvin (Feb. 1924) Director Power and Steam Survey Section, Philadelphia Co, 435 Sixth Ave, Pittsburgh, Pa; h, 1204 Fifth Ave, Coraopolis, Pa. . . . . **Grant 4300**

★**Alford, Newell Gilder** (Oct. 1922) Vice Pres, Eavenson, Alford & Hicks, 1300 Union Trust Bldg; h, 7145 Meade St, Pittsburgh, Pa. . . . . **Atlantic 3939**

Allan, David W. (Feb. 1924) Sales Mgr; Industrial Div, Fairmont Mining Machinery Co, 517 Clark Bldg; h, 1206 Rebecca Ave, Wilkinsburg, Pittsburgh, Pa. . . . . **Atlantic 9229**

ALLDERDICE, NORMAN (Chairman Aeronautic Section) (June 1915) Pres, Arch Machinery Co, Inc, 1001 Park Bldg; h, 5727 Wilkins Ave, Pittsburgh, Pa. . . . . **Atlantic 6430**

Allderdice, Taylor (Feb. 1917) 1001 Park Bldg; h, 5727 Wilkins Ave, Pittsburgh, Pa. . . . . **Atlantic 6430**

Allen, Harvey (Feb. 1903) Consulting Engineer, Private Practice; h, 347 Columbia Ave, West View, Pittsburgh, Pa. . . . . . **Wellington 1163-R**

Allen, J. Wallace (Dec. 1928) Chief Mech. Engr, Clairton By-Product Coke Works, Carnegie Steel Co, Clairton, Pa; h, 540 Mitchell Ave, Clairton, Pa. . . . . **Clairton 5**

Allen, Lewis C. (**Associate**) (March 1928) Sales Dept, Fairbanks Morse & Co, Cleveland, Ohio; h, Emerson Ave, Parkersburg, West Va.

Allewelt, Robert L. (March 1929) Sales Engr, General Electric Co, First National Bank Bldg, Youngstown, Ohio; h, 661 Wick Ave, Youngstown, Ohio.

Allison, John Harold (May 1921) Secretary, E. J. Deckman Co, 902 Oliver Bldg; h, 605-A Worth St, Pittsburgh, Pa. . . . . **Atlantic 1843**

Altsman, William H. (June 1928) Mech. Engr, Pittsburgh, Harmony, Butler & New Castle R. R, 602 Benedum-Trees Bldg; h, 67 Watsonia Blvd, N. S, Pittsburgh, Pa. . . . . **Court 0194**

Anderson, Burt T. (**Associate Member**) (Nov. 1928) Asst. to President, Union Switch & Signal Co, Swissvale, Pa; h, 6944 Thomas Blvd, Pittsburgh, Pa. . . . . **Penhurst 0880-Ext. 208**

Anderson, Walker (**Associate**) (Dec. 1926) Sales Engr, General Electric Co, Oliver Bldg; h, 1421 Walnut St, Edgewood, Pittsburgh, Pa. . . . . **Atlantic 6400**

Andrews, J. R. (March 1929) Designer, Aetna Standard Engineering Co, 1400 Chamber of Commerce Bldg, Pittsburgh, Pa; h, 700 Fourth St, Beaver, Pa. . . . . **Atlantic 9000**

Andrews, John, Jr. (May 1929) Dist. Mgr, Westinghouse Electric & Mfg. Co, 1800 Grant Bldg; h, 5556 Wellesley Ave, Pittsburgh, Pa. . . . . **Atlantic 8400**

Andrews, Roger W. (May 1921) Asst. to Pres, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, West Waldheim Road, Aspinwall Heights, Aspinwall, Pittsburgh, Pa. . . . . **Sterling 2700**

Andrews, William W. (June 1921) Civil & Mining Consulting Engr, 1200 Jones Law Bldg, Pittsburgh, Pa; h, 430 Beechwood Ave, Carnegie, Pa. . . . . **Court 0275**

Angle, James Macfarlane (Oct. 1919) Assoc. Highway Bridge Engr, U. S. Bureau of Public Roads, P. O. Box J, Shepperd Bldg, Montgomery, Ala; h, 201 Clayton St., Montgomery, Ala.

Angstrom, C. J. (May 1921) Mech. Engr, Mackintosh-Hemphill Co, Point Bldg; h, 237 Forest Ave, Bellevue, Pittsburgh, Pa. . . . . . **Court 3862**

Archer, Arthur A. (March 1928) Asst. Engr, Pittsburgh Coal Co, 1012 Oliver Bldg; h, 924 Timberland Ave, S. H, Pittsburgh, Pa. . . . . **Atlantic 2181**

List of Members

Archer, Robert B. (Junior) (March 1927) Bridge Designer, T. J. Wilkerson, County Engineer, Court House, Beaver, Pa; h, 329 College Ave, Beaver, Pa........................ **Beaver 1450**

Arensberg, Francis Louis (June 1911) Pres, Vesuvius Crucible Co, P. O. Box 47, Swissvale, Pa; h, 4739 Bayard St, Pittsburgh, Pa........................ **Brandywine 0107**

Armel, James Paul (June 1922) Sales Engr, Roeper Crane & Hoist Works, Inc, 323 Fulton Bldg; h, 466 Biddle Ave, Wilkinsburg, Pittsburgh, Pa........................ **Grant 4449**

★**Arras, John William** (Nov. 1888) Principal Engr, U. S. Government War (Eng'rg.) Dept, 1506 Keenan Bldg, Pittsburgh, Pa; h, Woodlawn Drive, Coraopolis, Pa........................ **Atlantic 5958**

Arrott, James W., Jr. (March 1892) Treasurer, James W. Arrott, Ltd, Arrott Bldg, Pittsburgh, Pa; h, Sewickley, Pa.......... **Court 2640**

Aston, James (March 1916) Professor of Mining & Metallurgy, Carnegie Inst. of Technology; h, 7315 Perrysville Ave, Ben Avon, Pittsburgh, Pa........................ **Mayflower 2600**

Atcherson, Ralph W. H. (May 1915) Blast Furnace Supt, Illinois Steel Co, Gary, Ind; h, 667 Van Buren St, Gary, Ind.

Atkinson, George H. (Nov. 1924) Chief Engr, G. H. Atkinson Co, 73 Eighth Ave, New York, N. Y; h, 150 W. 106th St, New York, N. Y.

Atwood, William Bartlett (June 1930) Pres, Atwood-Bradshaw Corp, 530 Fourth Ave; h, 910 California Ave, Avalon, Pittsburgh, Pa........................ **Court 2627**

Auburn, Basil J. (Associate) (Dec. 1924) Steel Mill Engr, Westinghouse Elec. & Mfg. Co, East Pittsburgh, Pa; h, 117 Penwood Ave, Edgewood, Pittsburgh, Pa........................ **Brandywine 1500**

Auchmuty, R. Laird (March 1928) Mining Engr, Eavenson, Alford & Hicks, 1300 Union Trust Bldg; h, 1228 Kelton Ave, Dormont, Pittsburgh, Pa........................ **Atlantic 3939**

Augustine, Charles Edward (March 1909) Assoc. Fuel Engr, U. S. Bureau of Mines, 4800 Forbes St; h, 7100 Upland St, Pittsburgh, Pa........................ **Mayflower 4500**

★**Auld, Elgie C.** (June 1915) Chief Engr, H. C. Frick Coke Co, P. O. Box 71, Scottdale, Pa; h, 1201 Loucks Ave, Scottdale, Pa..... **Scottdale 620**

Austin, Walter Merville (March 1919) Engr, Westinghouse Elec. & Mfg. Co, East Pittsburgh, Pa; h, 1527 Berkshire Ave, S. H, Pittsburgh, Pa........................ **Brandywine 1500**

Babb, Joseph E. (June 1922) Member of Firm, Falk & Co, Carnegie, Pa; h, 128 Linshaw Ave, Ingram, Pa.................. **Carnegie 860**

Bacharach, Herman (Nov. 1905) Pres, Bacharach Industrial Instrument Co, 7000 Bennett St; h, 6336 Phillips Ave, Pittsburgh, Pa........ ....**Montrose 0703**

Bachtel, Samuel Rowan (Sept. 1903; Nov. 1916) Vice Pres, Guibert Steel Co, P. O. Box 1037; h, 4012 Windsor St, Squirrel Hill, Pittsburgh, Pa..**Federal 2960**

Baer, Harry L. (March 1925) President, Water Treatment Co. of America, 2716 Grant Bldg; h, 2962 Crosby Ave, Dormont, Pittsburgh, Pa. ....**Atlantic 5490**

Bailey, John M. (May 1917) President, Standard Inspection Co, Martin Bldg, 119 Federal St; h, 916 California Ave, Avalon, Pittsburgh, Pa...**Fairfax 4982**

Baird, Hazen Virgil (Junior) (June 1928) Draftsman, Blum, Weldin & Co, 417 Grant St; h, c/o Downtown Y. M. C. A, Third & Wood St, Pittsburgh, Pa....................................**Court 4997**

Baker, David, Jr. (Jan. 1926) Metallurgical Engr, 1011 Chestnut St, Philadelphia, Pa; h, Orchard Way, Rosemont, Pa.

Baker, Thomas Stockham (Sept 1924) President, Carnegie Inst. of Technology; h, Pittsburgh Athletic Association, Pittsburgh, Pa........ ....**Mayflower 2600**

Baker, Walter H. (Sept 1916) Secy, Treas. & Genl. Mgr, Universal Steel Co, Bridgeville, Pa; h, 238 E. Wheeling St, Washington, Pa...... ....**Bridgeville 34**

Bakewell, Donald Campbell (April 1913) President, Duquesne Steel Fdry. Co, Union Bank Bldg, Pittsburgh, Pa; h, Sewickley, Pa.......... ....**Court 4938 or Coraopolis 505**

Ballard, Douglas Keene (Associate) (June 1923) Salesman, Kier Fire Brick Co, 1844 Oliver Bldg; h, Highland Terrace, Aspinwall, Pittsburgh, Pa..**Atlantic 0957**

Baltzell, Will H. (Dec. 1892) Chief Engr, Canadian Steel Corporation Ltd; h, Ojibway, Essex County, Ontario, Canada.

Bankson, Ellis E. (April 1926) Consulting Engr, The J. N. Chester Engineers, 813 Clark Bldg; h, 6562 Bartlett St, Pittsburgh, Pa........ ....**Atlantic 1140**

Barchfeld, Herman C. (March 1917) Mech. Engr, Concrete Products Co. of America, 712 Diamond Bank Bldg; h, 2402 Edgar St, Pittsburgh, Pa..**Atlantic 3841**

Barnes, Hugh Cooper (Jan. 1911) Mech. Engr, American Rolling Mill Co, Middletown, Ohio; h, Middletown, Ohio.

Barnes, Joseph F. (Nov. 1929) Asst. Secy, Eljer Co, Ford City, Pa; h, R. F. D. No. 3, Kittanning, Pa.

Barney, Harry (Associate Member) (April 1916) Pres. & Treas. Barney Machinery Co, Inc, Koppers Bldg; h, 1000 N. Highland Ave, Pittsburgh, Pa .... **Atlantic 4116**

Barnsley, George T., Jr. (Associate Member) (June 1914) Draftsman; h, Grace Dodge Hotel, Washington, D. C.

Barr, J. Carroll (Dec. 1924) President, Natrona Sand Co, also Contracting Engr, 616 Oliver Bldg; h, 4727 Wallingford St, Pittsburgh, Pa. .... **Atlantic 1825**

Barrett, Cecil Huitt (Associate Member) (May 1925) Asst. Designing Engr, Bureau of Engineering, City of Pittsburgh, 537 City-County Bldg; h, 3315 Francisco St, Pittsburgh, Pa ...... **Atlantic 3900-Ext. 158**

Barrett, James Marsh (May 1919) President, Polar Water Co, 939 West North Ave, Pittsburgh, Pa; h, Dutch Ridge Road, Beaver, Pa. .... **Cedar 8000**

Barrett, J. M. (March 1928) Manager Regulator Dept, Bailey Meter Co, Ivanhoe Road, Cleveland, Ohio; h, 3385 Fairmount Blvd, Cleveland Heights, Cleveland, Ohio.

Barry, T. J. (March 1924) Manufacturers' Representative, 1426 Park Bldg; h, 222 Parkman Ave, Pittsburgh, Pa .... **Atlantic 5193**

Bartholomew, Tracy (Feb. 1924) Mgr. of Research and Tests, Duquesne Slag Products Co, 704 Diamond Bank Bldg; h, 6668 Woodwell St, Pittsburgh, Pa .... **Atlantic 3841**

Batchelar, Eugene Croker (Feb. 1912) Dist. Mgr. Motch & Merryweather Machinery Co, 1315 Clark Bldg; h, 921 College Ave, Pittsburgh, Pa .... **Atlantic 3985**

Bates, Robert Paul (Junior) (Dec. 1928) Engineering Asst, Bell Telephone Co. of Pennsylvania, 630 William Penn Way; h, 1140 Tennessee Ave, Dormont, Pittsburgh, Pa .... **Official 0050-Ext. 106**

Baton, George Scott (Nov. 1916) President, Geo. S. Baton & Co, 2413 First National Bank Bldg; h, 326 S. Graham St, Pittsburgh, Pa .... **Atlantic 1576**

Bauer, Ralph G. (Oct. 1926) Engineering Secy, The Koppers Construction Co, Koppers Bldg; h, 46 S. Bryant Ave, Bellevue, Pittsburgh, Pa. .... **Atlantic 6240**

Baxter, James W. (May 1919) Mech. Engr, National Tube Co, Ellwood Works, Ellwood City, Pa.

Bay, Frederick R. (Dec. 1923) Vice Pres, The Bay Co, Bridgeport, Conn; h, 45 Prospect Place, New York, N. Y.

Beach, Willard J. (Jan. 1903) Engineer, Heyl & Patterson, Inc, Pittsburgh, Pa; h, P. O. Box 97, Perrysville, Pa .... **Court 0753**

Beatty, Floyd A. (Nov. 1925) Chief Engr, Lewis Fdry. & Machine Co, P. O. Box 1591; h, 3306 Allendale St, Corliss Sta, Pittsburgh, Pa. .... **Federal 3311**

Beatty, John David (Associate Member) (Feb. 1925) Secretary, Mining and Metallurgical Advisory Boards, Carnegie Inst. of Technology; h, 505 S. Lang Ave, Pittsburgh, Pa. .... **Mayflower 2600**

Beck, Herman (June 1927) Designer, Carnegie Steel Co, Duquesne Works; h, 11 S. 5th St, Duquesne, Pa. .... **Duquesne 5153**

Becker, Joseph (Jan. 1921) Vice Pres. and Genl. Mgr, The Koppers Construction Co, 1550 Koppers Bldg; h, Waldheim Road, Aspinwall, Pittsburgh, Pa. .... **Atlantic 6240**

Becker, Mathias (Associate Member) (Nov. 1922) Civil & Mining Engr, Private Practice; h, 375 Washington Ave., Leechburg, Pa. .... **Leechburg 275-W**

Beckwith, Homer E. (Associate Member) (April 1929) Dist. Mgr, Pitometer Co, Yoffee Bldg, Harrisburg, Pa; h, 2014 Mulberry St, Harrisburg, Pa.

Beerbower, Ralph C. (May 1930) Dist. Sales Mgr, Goodman Mfg. Co, 2218 Farmers Bank Bldg; h, 6901 Thomas Blvd, Pittsburgh, Pa. .... **Atlantic 2700**

Behar, M. F. (April 1930) Engineering Editor, "Instruments," 3619 Forbes St, Pittsburgh, Pa. .... **Schenley 6988**

Behney, C. C. (Dec. 1924) Dist. Representative, Simplex Valve & Meter Co, Hotel Harper Crest, Harper Ave. & 54th St, Chicago, Ill; h, 5405 Ingleside Ave, Chicago, Ill.

Beirne, Henry (Associate Member) (Oct. 1930) Inspection Engr, Allis-Chalmers Co, Columbus and Preble Sts, N. S; h, 4815 Baum Blvd, Pittsburgh, Pa. .... **Cedar 1070**

Bell, Frank B. (May 1921) President, Edgewater Steel Co, P. O. Box 249; h, 808 Devonshire St, Pittsburgh, Pa. .... **Oakmont 280**

Bell, George Gordon (April 1921) Manager Power Development, West Penn Electric Co, 14 Wood St; h, Pittsburgh Athletic Association, Pittsburgh, Pa. .... **Court 4106**

Bellows, Sidney R. (Associate Member) (Feb. 1925) Fire Protection Engr, Blackstone Mutual Fire Ins. Co, 1000 Grosvenor Bldg; h, 23 Tuzon Ave, Providence, R. I.

Benedict, John Blakesley (Associate) (Feb. 1926) Agent, The American Brass Co, 140 Federal St, Boston, Mass; h, 12 Commonwealth Ave, Boston, Mass.

Benn, Charles Leasure (Feb. 1925) Sales Engr, Peerless Heater Co, 5602 Baum Blvd; h, 227 Ruxton St, Pittsburgh, Pa. .... **Atlantic 0481**

Benner, Jacob W. (Sept. 1911) Supt. Employment, Safety & Welfare. Carnegie Steel Co, Homestead Steel Works, Munhall, Pa; h, 415 Neville St, Pittsburgh, Pa .... **Homestead 2603**

Bennett, Charles Wilbur (April 1920) Vice Pres, American Sheet & Tin Plate Co, 1321 Frick Bldg; h, 6300 Darlington Road, Pittsburgh, Pa .... **Atlantic 1300**

Berg, Hakon Axel (Nov. 1904) Sloss, Sheffield Steel & Iron Co, Birmingham, Ala.

★**Berg, John Daniel** (April 1914) Vice Pres, The Dravo Contracting Co, Dravo Bldg, 300 Penn Ave, Pittsburgh, Pa; h, Beaver Road, Glen Osborne, Pa .... **Court 5400**

Berger, John N. (June 1927) Mech. Draftsman, United Engrg. & Fdry. Co, 2426 Farmers Bank Bldg; h, 196 Locust St, Emsworth, Pittsburgh, Pa .... **Atlantic 0863**

★**Berger, Newell James (Associate Member)** (Oct. 1928) Owner, The Water Development Co, 447 Oliver Bldg, Pittsburgh, Pa; h, 2219 Frazier Ave, N. W, Canton, Ohio .... **Atlantic 0134**

Bernstein, Lester (Associate Member) (May 1925) Manager, Commercial Dev. Dept, Philadelphia Co, 435 Sixth Ave; h, 5678 Phillips Ave, Pittsburgh, Pa .... **Grant 3200**

Beymer, R. Alvin (Associate Member) (March 1930) Westinghouse Electric & Mfg. Co, Sharon, Pa; h, 425 South Ave, Wilkinsburg, Pittsburgh, Pa .... **Sharon 881**

Bickel, William D. (Dec. 1922) Pgh. Dist. Rep, The Allen-Sherman-Hoff Co; Ross Heater & Mfg. Co, 508 State Theatre Bldg; h, 418 S. Aiken Ave, Pittsburgh, Pa .... **Atlantic 1565**

Bigelow, Charles Glenford (May 1922) Research Engr, Inland Steel Co, Indiana Harbor, Ind; h, 1644 S. Herman St, Hammond, Ind.

★**Biggert, Florence C., Jr.** (April 1903) Vice Pres. and Senior Engr, United Engrg. & Fdry. Co, Farmers Bank Bldg; h, 108 Hawthorne Ave, Crafton, Pittsburgh, Pa .... **Atlantic 0863**

Billheimer, C. R. (Feb. 1927) Elec. Engr, West Penn Power Co, 14 Wood St; h, 817 Trenton Ave, Wilkinsburg, Pittsburgh, Pa .... **Court 4106**

Bingay, Robert V. (Dec. 1926) President, Stove & Range Co. of Pittsburgh, Preble Ave, N. S; h, Perrysville, Pa .... **Cedar 1520**

Bingham, William Charles (Feb. 1930) Proprietor, Bingham Metal Co, 720 Bakewell Bldg; h, 542 East End Ave, Pittsburgh, Pa .... **Court 1636**

Binnall, Frederick Clifford (March 1923) Dusseldorf, Germany.

Bishop, Frederick Lendall (Jan. 1912) Professor of Physics, University of Pittsburgh; h, Fox Chapel Manor, Aspinwall, Pittsburgh, Pa. .... **Mayflower 3500**

Bisler, Walter Edward (Associate Member) (Oct. 1924) Sales Engr, Combustion Engineering Corp, 1606 First National Bank Bldg; h, 229 Beverly Road, Mt. Lebanon, Pittsburgh, Pa.........**Atlantic 1511**

Bixby, William Peet (May 1930) Sales Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, Waldheim Road, Aspinwall, Pittsburgh, Pa...**Sterling 2700**

Black, Robert Moffitt (May 1921) Professor and Head of Mining Dept, University of Pittsburgh; h, 3732 Dawson St, Pittsburgh, Pa. ....**Mayflower 3500**

Blair, George Sheppard (May 1927) Buildings Supervisor, Bell Telephone Co. of Penna, 416 Seventh Ave; h, 116 S. Harrison Ave, Bellevue, Pittsburgh, Pa.................................**Official 0050**

Blaisdell, Allen H. (June 1929) Associate Prof. of Mechanical Engineering, Carnegie Inst. of Technology; h, 939 Trenton Ave, Wilkinsburg, Pittsburgh, Pa...............................**Mayflower 2600**

Blake, A. Wade (Oct. 1929) Sales Engr, Consolidated Ashcroft Hancock Co, 1411 Park Bldg; h, 524 Hillcrest Place, Mt. Lebanon, Pittsburgh, Pa...**Atlantic 6330**

Blanton, Hennen J. (Dec. 1924) Asst. Engr, Boiler Division, Combustion Engineering Corp, 200 Madison Ave, New York, N. Y; h, 8829 Fort Hamilton Parkway, Brooklyn, N. Y.

Blenko, Walter J. (Dec. 1924) Member of Firm, Byrnes, Stebbins, Parmalee & Blenko, 1319 Farmers Bank Bldg; h, 4338 Luster St, Pittsburgh, Pa...**Atlantic 1609**

Blest, Minot C. (Dec. 1902) Chief Engr, Pressed Steel Car Co, Farmers Bank Bldg; h, 1011 California Ave, Avalon, Pittsburgh, Pa........ ....**Federal 0740**

Blickle, Herman Renner (May 1910) Vice Pres, Fort Pitt Bridge Works, Oliver Bldg; h, 5434 Dunmoyle Ave, Pittsburgh, Pa..**Atlantic 0654**

Bloom, Frederick Sturate (Oct. 1924) Engineer, Costello Engineering Co, 519 Oliver Bldg; h, 380 Orchard Drive, Mt. Lebanon, Pittsburgh Pa...**Atlantic 1493**

Bloomquist, O. A. (March 1926) Address unknown.

★**Blum, Louis P.** (Jan. 1903) Partner, Blum, Weldin & Co, Bakewell Bldg, 417 Grant St; h, 3070 Watson Entrance, N. S, Pittsburgh, Pa. ....**Court 4997-8**

Boardman, Charles Slauson (Feb. 1929) Contracting Engr, Jones & Laughlin Steel Corp, Steel Piling Dept, Third & Ross St; h, 520 St. James Place, Pittsburgh, Pa.........................**Court 3240**

Bode, John Henry (Dec. 1915) Sales Engr, Aetna Standard Engineering Co, Home Savings Bldg, Youngstown, Ohio; h, 3415 Idlewood Ave, Youngstown, Ohio.

Bohn, Donald Ivan (Dec. 1928) Electrical Engr, Aluminum Co. of America, 2400 Oliver Bldg; h, 124 Newburn Drive, Mt. Lebanon, Pittsburgh, Pa.................................... **Atlantic 4545**

Boleky, E. J., Jr. (**Student Junior**) (May 1930) Student, University of Pittsburgh; h, 125 Roosevelt Road, Emsworth, Pa...... **Linden 3297-R**

Bonsall, Judson (May 1927) Supt. Compressing Stations, Equitable Gas Co. and Pittsburgh & West Virginia Gas Co, 604 Union Bank Bldg; Clarksburg, West Va; h, 509 Milford St, Clarksburg, West Va.

Boothman, Dale Maxwell (Jan. 1921) Mech. Engr, Research Bureau, Aluminum Co. of America, New Kensington, Pa; h, 223 Eighth Ave, Oakmont, Pa.......................... **New Kensington 8**

Borg, John Edward (May 1925) Chief Draftsman, Julian Kennedy, Jr, 1217 Bessemer Bldg; h, 232 Martsolf Ave, West View, Pittsburgh Pa.. **Atlantic 7730**

Botsai, Louis Roderick (Nov. 1923) Gearing Apparatus Mgr, Nuttall Works, Westinghouse Elec. & Mfg. Co, 200 McCandless Ave, Pittsburgh, Pa; h, Clover Club, 6744 Penn Ave, Pittsburgh, Pa.. **Fisk 1224**

Bott, Clarence C. (**Associate Member**) (March 1930) Salesman, Leeds & Northrup Co, 1228 Union Trust Bldg, Cleveland, Ohio; h, 9806 Woodward Ave, Cleveland, Ohio.

Bowers, Edwin C. (**Associate**) (March 1912) Manager, No. 6 Plant, Libbey-Owens-Ford Glass Co, Rossford, Ohio; h, Eagle Point Colony, Rossford, Ohio.

Bowman, Franklin Meyer (April 1893) Vice Pres, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 1234 N. Highland Ave, Pittsburgh, Pa.. **Sterling 2700**

Boyd, John Ridinger (June 1912; Nov. 1922) Designing Engr, P.&L.E.R.R. Room 500, P.&L.E. Terminal Bldg; h, 1454 Alabama Ave, S. H. Sta, Pittsburgh, Pa........................ **Court 3201-Ext. 181**

Boyd, W. Wallace (Nov. 1928) Chief Engr, Standard Scale & Supply Co, Beaver Falls, Pa; h, 628 Beaver St, Sewickley, Pa.. **Beaver Falls 180**

Boyle, Walter William (May 1921) Supt. Buildings and Equipment, Joseph Horne Co; h, 512 McCully St, Mt. Lebanon, Pittsburgh, Pa...... .... **Court 3000**

Boyle, William George (May 1921) Engineer, Henry W. Oliver Estate, 423 Oliver Bldg, Pittsburgh, Pa; h, Bakerstown, Pa... **Atlantic 0100**

Bracken, Michael Joseph (Feb. 1905) President, Argyle Coal Co, 606 First National Bank Bldg, Johnstown, Pa; h, 1071 McKinley Ave. Johnstown, Pa.

Braden, Earle Vance (June 1911) Chief Engr, Pittsburgh, Chartiers & Youghiogheny Rwy. Co. and Engr. of Construction, Monongahela Rwy. Co, 1200 Century Bldg; h, 38 East Steuben Ave, Crafton, Pittsburgh, Pa . . . . **Atlantic 5244**

Bradford, H. H. (**Associate Member**) (Jan. 1923) Institutional Finance Director, Ketchum Inc, 2020 Koppers Bldg; h, 6 Highland Court, 5637 Callowhill St, Pittsburgh, Pa . . . . **Atlantic 1100**

Bradley, John Rodgers (Oct. 1926) Vice Pres, Duff Patents Co, Inc, 991 Union Trust Bldg; h, 114 Washington Ave, Bellevue, Pittsburgh, Pa . . . . **Atlantic 5235**

★**Bradshaw, Grant D.** (July 1916) President, Bradshaw & Co, 530 Fourth Ave, Pittsburgh, Pa; h, 186 Beaver St, Beaver, Pa . . . . . **Court 2627**

Brady, Hugh S. (Feb. 1928) Dist. Mgr, Hazel-Atlas Glass Co, 16th & Market Sts, Wheeling, West Va; h, Howard Place, Wheeling, West Va.

★**Brandt, Edgar C.** (March 1917) Assistant Works Mgr, Westinghouse Elec. & Mfg. Co, East Pittsburgh, Pa; h, 1204 Milton Ave, Regent Square, Swissvale, Pittsburgh, Pa . . . . **Brandywine 1500**

Branson, Craig Ridgway (May 1903) Mech. Inspector, Pennsylvania R. R. Room 600, Union Station, Chicago, Ill; h, 6532 Greenwood Ave, Chicago, Ill.

Braun, William Paul (April 1928) Asst. Engr, Blum, Weldin & Co, Bakewell Bldg, 417 Grant St; h, 2929 Parkdale Ave, Carrick, Pittsburgh, Pa . . . . **Court 4997**

Bray, James M. (April 1911) Representative & Roll Designer, United Engrg. & Fdry. Co, Farmers Bank Bldg; h, 6035 Bunker Hill Road, Pittsburgh, Pa . . . . **Atlantic 0863**

★**Bray, Thomas Joseph** (June 1902) h, 1510 Fifth Ave, Youngstown, Ohio.

Breisky, John V. (**Associate Member**) (Sept. 1929) Section Engr, Supply Engrg. Dept, Westinghouse Elec. & Mfg. Co, East Pittsburgh, Pa; h, 7505 Rosemary St, Pittsburgh, Pa . . . . **Brandywine 1500**

★**Brigel, Samuel G.** (May 1902) h, 1127 N. Highland Ave, Pittsburgh, Pa.

Bright, Graham (Dec. 1923) Sales Engr, Mine Safety Appliances Co, Braddock Ave. & Thomas Blvd; h, 20 Bryn Mawr Road, Wilkinsburg, Pittsburgh, Pa . . . . **Churchill 5900**

Brinker, Harry Louis (Oct. 1913) Works Supt, Brier Hill Works, Youngstown Sheet & Tube Co, Youngstown, Ohio; h, 255 Arlington St, Youngstown, Ohio.

Britton, J. Robert (**Student Junior**) (Dec. 1928) 740 Broughton St, Pittsburgh, Pa.

Broden, Edwin R. (**Junior**) (Nov. 1929) Power Division Engrg. Dept, American Sheet & Tin Plate Co, 1228 Frick Bldg; h, 132 Hawthorne St, Edgewood, Pittsburgh, Pa . . . . **Atlantic 1300**

Brooks, Joseph Bradford (Sept. 1918) Draftsman, Bureau of Bridges, Allegheny County, 519 Smithfield St; h, 424 Lloyd St, Homewood Station, Pittsburgh, Pa . . . . **Atlantic 4900-Ext. 320**

Brosius, Edgar E. (Jan. 1912) President, Edgar E. Brosius, Inc, Sharpsburg, Pa; h, 6550 Beacon St, Pittsburgh, Pa . . . . **Sterling 2086**

Brown, Charles F. (March 1923) Construction Engr, Bureau of Water, City of Pittsburgh, 531 City-County Bldg; h, 508 Rossmore Ave, Pittsburgh, Pa . . . . **Atlantic 3900-Ext. 200**

Brown, Edwin Corner (Nov. 1906) Chief Civil Engr, Carnegie Steel Co, 1012 Carnegie Bldg; h, 210 Maple Ave, Edgewood, Pittsburgh, Pa . . . . **Atlantic 5100**

Brown, Harry D. (June 1912) Draftsman, National Tube Co, McKeesport, Pa; h, 519 S. Lang Ave, Pittsburgh, Pa . . . . **McKeesport 4144**

Brown, Herbert Vincent (Dec. 1928) President, The Brown-Fayro Co, 940 Ash St, Johnstown, Pa; h, 623 Luzerne St, Johnstown, Pa.

Brown, James M. (Dec. 1927) Sales Engr, Surface Combustion Co, Inc, 619 Oliver Bldg; h, 3755 Beechwood Blvd, Pittsburgh, Pa . . . . **Atlantic 9191**

Brown, John T., Jr. (June 1911) Supt, Duquesne Reduction Co, Gross & Yew Sts; h, 6667 Woodwell St, Pittsburgh, Pa . . . . . . **Schenley 2410**

Brown, Norman Fred (Nov. 1903) Director, Dept. of Public Works, Allegheny County, 519 Smithfield St; h, 707 Amberson Ave, Pittsburgh, Pa . . . . **Atlantic 4900-Ext. 240**

Brown, William Edward (**Associate Member**) (April 1926) Chief Engr, The Vang Construction Co, 3022 Grant Bldg; h, Cathedral Mansions, Pittsburgh, Pa . . . . **Grant 8520**

Bruner, William J. (Jan. 1922) Asst. Engr, Heyl & Patterson, Inc, 49-53 Water St; h, 3254 Orleans St, Pittsburgh, Pa . . . . **Court 0753**

Bryan, Joseph (April 1925) Asst. Mgr, General Electric Co, 1315 Oliver Bldg; h, 1147 Wightman St, Pittsburgh, Pa . . . . **Atlantic 6400**

Buell, Frank T. (Nov. 1927) Special Agent, Connecticut Genl. Life Insurance Co, 1309 Park Bldg; h, 211 Jucunda St, Mt. Oliver Station, Pittsburgh, Pa . . . . **Atlantic 0400**

★**Buell, William C., Jr.** (May 1920) c/o Arthur G. McKee Co, Cleveland, Ohio; h, Allerton Hotel, Cleveland, Ohio.

Buente, Charles F. (Jan. 1887; April 1916) Secy. Concrete Products Co. of America, Diamond Bank Bldg; h, 2721 Miles Ave, Dormont, Pittsburgh, Pa . . . . **Atlantic 3841**

BUENTE, WILLARD HARRISON (Chairman Practicing Engineers' Section) (Oct. 1915) Chief Engr, The W. G. Wilkins Co, 909 Westinghouse Bldg; h, 3525 Diploma St, N. S, Pittsburgh, Pa . . **Atlantic 4141**

Buenting, Otto W. (Dec. 1927) Vice Pres. Westinghouse Air Brake Co. and Vice Pres. Union Switch & Signal Co, Swissvale, Pa; h, 512 East End Ave, Pittsburgh, Pa . . . . **Penhurst 0880**

Buerger, Charles B. (March 1927) Vice Pres, Gulf Refining Co, P. O. Box 1214, Frick Bldg. Annex; h, 120 Ruskin Ave, Pittsburgh, Pa . . . . **Atlantic 5300**

Buhl, William (Associate Member) (March 1927) Sales Engr, Dravo-Doyle Co, 300 Penn Ave; h, 1458 Grandin Ave, Dormont, Pittsburgh, Pa . . . . **Court 5400**

Bulmer, William Carr (Nov. 1928) Sales Engr, Blaw-Knox Co, P. O. Box, 915, Pittsburgh, Pa; h, 419 Lexington Ave, Aspinwall, Pittsburgh, Pa . . . . **Sterling 2700**

Burgess, Charles Calvin (March 1923) Oper. Mgr. & Consulting Engr, Duquesne Slag Products Co, 810 Diamond Bank Bldg; h, 6842 Thomas Blvd, Pittsburgh, Pa . . . . **Atlantic 3841-Ext. 283**

Burgess, Henry Russell (Junior) (Feb. 1927) Engineer, H. H. Robertson Co, Grant Bldg; h, 6842 Thomas Blvd, Pittsburgh, Pa . . . . **Atlantic 3200**

Burns, Stewart H. (April 1921) Boro Engr, Millvale, Etna & Sharpsburg; h, 518 North Ave, Millvale, Pa . . . . **Millvale 1185**

Burr, Robert B. (May 1913) Industrial Engr, Georgia Natural Gas Corp, 245 Peachtree St, Atlanta, Ga; h, Apt. 7, 183 Poplar Circle, Atlanta, Ga.

Burton, John Earl (Associate Member) (March 1928) Proprietor, Prosperity Sales Service Co, 112 Washington St; h, 1138 Brookline Blvd, Pittsburgh, Pa . . . . **Atlantic 0892**

Bushnell, Carl D. (May 1921) President, The Bushnell Machinery Co, 1501 Grant Bldg, Pittsburgh, Pa; h, Rosslyn Farms, Carnegie, Pa. . . . . **Atlantic 0417**

Butler, A. G. (Nov. 1929) Branch Mgr, Byllesby Engineering & Management Corp, 435 Sixth Ave; h, 5533 Beverly Place, Pittsburgh, Pa . . . . **Grant 5750-Ext. 557**

★**Butler, Richard Ellis (Associate Member)** (April 1921) Vice Pres, Rust Engineering Co, Koppers Bldg; h, 515 Amberson Ave, Pittsburgh, Pa . . . . **Atlantic 8870**

Butt, F. H. (**Associate Member**) (April 1930) Sales Correspondent, Westinghouse Elec. & Mfg. Co, East Pittsburgh, Pa; h, 434 McCully St, Mt. Lebanon, Pittsburgh, Pa.................. **Brandywine 1500**

Buxton, Jay James (**Associate Member**) (June 1923) Dist. Supt of Erection, The Babcock & Wilcox Co. 2730 Koppers Bldg; h, 65 Craighead St, Pittsburgh, Pa............................ **Atlantic 0672**

Buys, Orville (**Associate**) (Dec. 1928) President, Buys Engineering Co, 62 Vandergrift Bldg; h, 32 Nickolson St, Crafton, Pittsburgh, Pa. .... **Court 1620**

Byrne, William Luke (Nov. 1929) Mftrs'. Rep, Air Engineering Equipment, 4 Smithfield St; h, 5843 Bartlett St, Pittsburgh, Pa.... **Court 5697**

Byrnes, Charles J. (Sept. 1917) Structural Designer, The Koppers Construction Co, Koppers Bldg; h, 7120 Mt. Vernon St, Pittsburgh, Pa.. **Atlantic 6240**

Cadman, Alexander M. (Jan. 1925) Secy. & Treas, A. W. Cadman Mfg. Co, 2814-16 Smallman St, Pittsburgh, Pa; h, 349 Maple Ave, Edgewood, Pittsburgh, Pa.................................. **Atlantic 6683**

Cadmann, M. McW. (Jan. 1903) Chemist, Carnegie Steel Co, 821 Carnegie Bldg; h, Edgewood, Pittsburgh, Pa................. **Atlantic 5100**

Cadwallader, James A. (Jan. 1930) Engr. of Transmission & Outside Plant, The Bell Telephone Co. of Penna, 416 Seventh Ave; h, 1416 Park Blvd, Dormont, Pittsburgh, Pa..................... **Official 0050**

Caffal, Geoffrey Arthur (Feb. 1927) Mgr. of Erection, McClintic-Marshall Co. 1324 Oliver Bldg; h, King Edward Apts. Pittsburgh, Pa...... .... **Atlantic 2562**

Caldwell, Paul (Nov. 1923) Sales Engr, General Electric Co, 1314 Oliver Bldg; h, 600 Gettysburg St, Pittsburgh, Pa.......... **Atlantic 6400**

Callery, James D. (Feb. 1916) President, Diamond National Bank, Fifth & Liberty Aves; h, 718 Devonshire St, Pittsburgh, Pa.. **Atlantic 3475**

Cameron, Harry E. (**Associate Member**) (April 1928) Designing Engr, American Bridge Co, 1420 Frick Bldg; h, 1209 Peermont Ave, Dormont, Pittsburgh, Pa.......................... **Atlantic 4300**

Campbell, John T. (March 1923) Member of Firm, The J. N. Chester Engineers, 813 Clark Bldg; 6627 Church Ave, Ben Avon, Pittsburgh, Pa.. **Atlantic 1140**

Campbell, R. D. (Sept. 1924) Vice. Pres, Allegheny Steel Co, Brackenridge, Pa; h, 1345 Inverness Ave, Pittsburgh, Pa............ **Grant 2766**

Canan, W. D. (**Associate Member**) (Oct. 1925) Mech. Engr, Rust Engineering Co, Koppers Bldg; h, 1215 Walnut St, Wilkinsburg, Pittsburgh, Pa.................................... **Atlantic 8870**

Candy, A. M. (Dec. 1928) Genl. Engr, Westinghouse Elec. & Mfg. Co, East Pittsburgh, Pa; h, 1108 Sherman St, Wilkinsburg, Pittsburgh, Pa.......................................**Brandywine 1500**

Carlock, John Bruce (Oct. 1928) Chief Engr, Jones & Laughlin Steel Corp, 27th & Carson Sts, S. S; h, 5429 Bartlett St, Pittsburgh, Pa...**Hemlock 0401**

Carlson, Clifford E. (**Junior**) (Dec. 1928) Asst. Supt, National Valve & Mfg. Co, 3101 Liberty Ave, Pittsburgh, Pa; h, 111 Pennsylvania Ave, Oakmont, Pa...............................**Atlantic 6730**

Carlson, Earle Charles (**Junior**) (March 1927) Address unknown.

Carnes, William K. (Oct. 1911; Feb. 1926) Asst. Chief Engr, Schoen Works, Carnegie Steel Co, McKees Rocks, Pa; h, 23 Emerson Ave, Crafton, Pittsburgh, Pa.................................**Federal 1061**

★**Carpenter, Charles A.** (March 1922) Mftr's. Rep. & Partner, Starr-Carpenter, 1124 Park Bldg; h, 5634 Hampton St, Pittsburgh, Pa. ....**Atlantic 1488**

Carr, John Crozier (Dec. 1905) Employment Supt, Jones & Laughlin Steel Corp, S. 27th & Carson Sts; h, 56 Parke St, Crafton, Pittsburgh, Pa...**Hemlock 0401**

Carr, Uhel U. (Jan. 1925) Genl. Mgr, Diamond Machine Co, P. O. Box 411, Monongahela, Pa; h, 900 Sheridan St, Monongahela, Pa.......... ....**Monongahela 9**

Carten, Charles N. (Feb. 1912) Senior Asst. Engr, Bureau of Water, City of Pittsburgh, City-County Bldg; h, 400 S. Linden Ave, Pittsburgh, Pa...**Atlantic 3900**

Carter, Edgar Levis (**Associate Member**) (Oct. 1928) Timekeeper S. M. Siesel Co, 542 Diamond St; h, 215 N. Craig St, Pittsburgh, Pa. ....**Grant 4091**

Cary, Emmet Foster (March 1929) Sales Mgr, Coupling Div, The Bartlett Hayward Co, Baltimore, Md; h, 2315 Chelsea Terrace, Baltimore, Md.

Casey, John F. (March 1924) President, John F. Casey Co, P. O. Box 1753, h, 4789 Wallingford St, Pittsburgh, Pa..............**Sterling 1400**

Chalfant, Frederick Bernard (Nov. 1913) Div. Engr, Div. of Surveys, City of Pittsburgh, City-County Bldg; h, 5556 Avondale Place, Pittsburgh, Pa...................................**Atlantic 3900**

★**Chandler, Willard P., Jr.** (June 1914; Feb. 1918) Chief Engr, Furnace Div, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 426 S. Linden Ave, Pittsburgh, Pa.............................**Sterling 2700**

Chaney, George Scott (April 1925) County Engr. Washington County, Court House, Washington, Pa; h, 549 E. Chestnut St, Washington, Pa.

Chapman, William B. (June 1922) President, Chapman Engineering Co, 50 Church St, New York, N. Y; h, 155-24th St, Jackson Heights, Long Island, N. Y.

Charles, Howard B. (**Associate**) (April 1924) Secy. & Treas, Industrial Paint Co, 1444 Oliver Bldg; h, 522 Hill Ave, Wilkinsburg, Pittsburgh, Pa.......................................**Atlantic 2954**

Chartener, Victor, Jr. (May 1925) Asst. Chief Engr, Pittsburgh Steel Co, Monessen, Pa; h, 414 Park Way, Monessen, Pa......**Monessen 360**

Cherrington, George H. (Feb. 1913) President, Machinists Supply Co, and Brown & Zortman Machinery Co, 325 Blvd. of the Allies; h, 5851 Marlborough St, Pittsburgh, Pa.................**Court 0890**

★**CHESTER, JOHN NEEDELS** (**Past President 1929**) (Dec. 1896) Senior Partner, The J. N. Chester Engineers, 813 Clark Bldg, Pittsburgh, Pa...**Atlantic 1140**

★**Chester, Wilfred Dudley** (April 1900) Retired; h, 238 Thorn St, Sewickley, Pa.

★**Chesterman, Francis John** (Jan. 1928) Vice Pres. & Genl. Mgr, The Bell Telephone Co. of Penna, 416 Seventh Ave; h, 205 Lytton Ave, Pittsburgh, Pa.................................**Official 0050**

Chew, Robert E. (**Associate**) (May 1929) Vice Pres. and Genl. Mgr. Ladd Equipment Co, 2428 Farmers Bank Bldg; h, 265 Cochran Road, Mt. Lebanon, Pittsburgh, Pa.......................**Atlantic 1984**

Chickering, Tileston (Feb. 1911) Estimator, Carnegie Steel Co, 427 Carnegie Bldg, Pittsburgh, Pa; h, 1445 Beaver Road, Glen Osborne, Sewickley, Pa..............................**Atlantic 5100**

Christianson, Andrew (**Associate Member**) (Nov. 1912) Chief Engr, Standard Steel Car Co, Pittsburgh, Pa; h, P. O. Box 877, Butler, Pa...**Atlantic 1833**

Christie, Lindsay R. (Sept. 1928) President, L. R. Christie Co, Union Trust Bldg; h, King Edward Apts, Pittsburgh, Pa.....**Atlantic 4465**

Christy, George Lewis (Feb. 1915) Chief Engr, Pittsburgh-Des Moines Steel Co, Neville Island; h, 5586 Pocussett St, Pittsburgh, Pa. ....**Federal 3000**

Church, Walter S. (Dec. 1912) Asst. Supt. Bldg. & Mech. Dept, Byllesby Engineering & Management Corp, 435 Sixth Ave; h, 6413 Jackson St, Pittsburgh, Pa........................**Grant 5750-Ext. 569**

Clagett, Thomas H. (Nov. 1902; April 1916) Chief Engr, Pocahontas Coal & Coke Co, P. O. Box 617, Bluefield, West Va.

Clark, Charles H. (May 1921) Engineer, Allerton Hotel, Cleveland, Ohio; h, Library Road, Library, Pa .... **Library 59**

Clark, Eben B. (May 1903) Vice Pres, Firth-Sterling Steel Co, Oliver Bldg; h, Morewood Gardens, Pittsburgh, Pa .... **Atlantic 0471**

Clark, Milnor P. (Feb. 1900) Manager, E. I. Clark Hardware Co, 1213 Fifth Ave, McKeesport, Pa; h, 1408 Bailey Ave, McKeesport, Pa .... **McKeesport 20957**

Clause, William L. (March 1921) Chairman Board of Directors, Pittsburgh Plate Glass Co, 2206 Grant Bldg, Pittsburgh, Pa; h, Creek Drive, Sewickley, Pa .... **Atlantic 5600**

Clement, Albert E. (**Associate Member**) (Dec. 1927) Engineer, Natrona Light & Power Co, and Natrona Water Co, Natrona, Pa; h, Fourth Ave, Natrona Heights, Natrona, Pa .... **Tarentum 1507**

Clifford, Thomas C. (Feb. 1914) Asst. Mgr, Refrigeration Dept, Westinghouse Electric & Mfg. Co, 200 E. Fifth St, Mansfield, Ohio; h, 145 Park Ave, West, Mansfield, Ohio.

Cline, John Russell (April 1920) Asst. Supt, Universal-Atlas Cement Co, Universal, Pa; h, 8920 Upland Terrace, Wilkinsburg, Pittsburgh, Pa .... **Unity 8**

Cochran, John S. (July 1910) President, Mac-It Parts Co, Lancaster, Pa; h, Lancaster, Pa.

Cogswell, Frederick R. (**Associate Member**) (May 1921) Director, Traffic Promotion, Pittsburgh Railways Co, 435 Sixth Ave; h, 5716 Solway St, Pittsburgh, Pa .... **Grant 7450-Ext. 149**

Colburn, George M. (Sept. 1930) Industrial Engr, Edgar Thomson Works, Carnegie Steel Co, Braddock, Pa; h, 129 Good St, Jeannette, Pa. .... **Brandywine 2590**

Cole, Henry Ernest (April 1910) President, Harris Pump & Supply Co, 320 Second Ave; h, 6100 Stanton Ave, Pittsburgh, Pa .. **Court 3800**

Cole, Herbert F. (Nov. 1925) In Charge Small Industrial Sales, General Electric Co, 1318 Oliver Bldg; h, 44 Academy Ave, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 6400**

Colgan, Charles Judson (Dec. 1924) Research Engr, Monongahela West Penn Public Service Co, Fairmont, West Va.

Collord, George L. (May 1921) Vice Pres, The Shenango Furnace Co, 812 Oliver Bldg, P. O. Box 1106; h, 808 Morewood Ave, Pittsburgh, Pa .... **Atlantic 0987**

Comstock, Glenn Moore (Nov. 1924) Sales Mgr, and Chief Engr, Rush Machinery Co, 3565 Bigelow Blvd, Pittsburgh, Pa; h, 154 College Ave, Beaver, Pa .... **Schenley 7600**

Connar, V. N. (March 1929) Eastern Manager, Service Bureau, Universal Atlas Cement Co, 516 Frick Bldg; h, 9 Hawthorne Ave, Crafton, Pittsburgh, Pa. . . . . **Atlantic 2087**

Connell, Howard R. (Dec. 1924) General Electric Co, P. O. Box 535, Brackenridge, Pa; h, 1108 Park St, Tarentum, Pa. . . . . . . **Tarentum 1000**

Connelley, Clifford Brown (May 1891) Secy-Treas, Marine Mfg. & Supply Co, 35 Water St; h, 300 Marsonia Ave, N. S, Pittsburgh, Pa. . . . . **Court 4200**

Connor, Francis A. (Nov. 1927) Sales Engr, General Electric Co, 1318 Oliver Bldg; h, 34 Academy Ave, S. H, Pittsburgh, Pa. . **Atlantic 6400**

Conway, Leon Francis (Associate Member) (Oct. 1930) Engineer, Crucible Steel Co, Park Works, 30th & Smallman Sts; h, 621 N. Euclid Ave, Pittsburgh, Pa. . . . . **Atlantic 8620**

Cook, Charles C. (March 1917) Maintenance Engr, Baltimore & Ohio R. R. Co, 1201 Baltimore & Ohio Bldg, Baltimore, Md; h, 3537 Liberty Heights Ave, Baltimore, Md.

Cook, John Orth (Associate Member) (Oct. 1929) Draftsman, Allegheny County, Dept. of Public Works, Room 102, 519 Smithfield St; h, 544 Rossmore Ave, S. H, Pittsburgh, Pa. . . . **Atlantic 4900-Ext. 156**

Cooke, M. W. (Dec. 1926) Supt. of Traffic, Pittsburgh Railways Co, 435 Sixth Ave; h, 221 Parker Drive, Mt. Lebanon, Pittsburgh, Pa. . . . . **Grant 7450-Ext. 162**

Coolidge, G. Greer, (Jan. 1912) Asst. Genl. Sales Mgr, Harbison-Walker Refractories Co, Farmers Bank Bldg; h, 5440 Aylesboro Ave, Pittsburgh, Pa. . . . . **Atlantic 0942**

Cooper, Frederick M. (April 1921) Civil Engr, Edeburn Cooper Co, Law & Finance Bldg, 429 Fourth Ave, Pittsburgh, Pa; h, Rose St, Coraopolis, Pa. . . . . **Atlantic 0898**

Cooper, Howell C. (Jan. 1923) Vice Pres. and Chief Engr, Hope Natural Gas Co, 545 William Penn Way; h, 232 Little St, Sewickley, Pa. . . . . **Grant 5100**

Cooper, Leroy Warrick (May 1927) Genl. Supt. Mines, West Penn Power Co, 14 Wood St, Pittsburgh, Pa; h, 1208 LaClair Ave, Swissvale, Pittsburgh, Pa. . . . . **Court 4106**

★**Cooper, Maurice Diehl** (Oct. 1916; Oct. 1926) Div. Genl. Supt, Hillman Coal & Coke Co, 2304 First National Bank Bldg; h, 5430 Aylesboro Ave, Pittsburgh, Pa. . . . . **Atlantic 2620**

Corbett, William J. (Nov. 1930) Asst. to President, Fort Pitt Steel Casting Co, McKeesport, Pa; h, 107 Biddle Ave, Wilkinsburg, Pittsburgh, Pa. . . . . **McKeesport 5186**

Corey, William Ellis (May 1897) Director, Bethlehem Steel Corp, 25 Broadway, New York, N. Y; h, 991 Fifth Ave, New York, N. Y.

Cornelius, Henry R. (Dec. 1911) Sales Engr, Mesta Machine Co, 1943 Oliver Bldg, Pittsburgh, Pa; h, R. D. No. 1, Coraopolis, Pa...... .... **Atlantic 1472**

Coryell, William Clayton (Nov. 1914) Consulting Engr, 1719 Ohio Ave, Youngstown, Ohio.

Cosgrove, William H. (Nov. 1922) Vice Pres, Swindell Dressler Co, Freeport Road, Aspinwall, Pa, P. O. Box 1753; h, 5712 Howe St, Pittsburgh, Pa.................................... **Sterling 1400**

Coslow, Carl W. (Dec. 1928) President, Erie Nash Inc, 138 East 12 th St, Erie, Pa; h, 4435 Cherry St, Erie, Pa.

Cott, Parker (April 1925) Field Representative, American Mining Congress Journal, Washington, D. C, also Mgr. Pittsburgh Branch, Scranton Pump Co, 406 Empire Bldg; h, 6345 Glenview Place, Pittsburgh, Pa.. **Atlantic 6348**

Cotter, George L. (**Associate Member**) (Jan. 1925) Dist. Engr, Westinghouse Air Brake Co; h, 353 Marguerite Ave, Wilmerding, Pa. .... **Brandywine 1490-Ext. 311**

★**Covell, Vernon Royce** (Nov. 1897) Chief Engr, Bureau of Bridges, Dept. Public Works, Allegheny Co, 519 Smithfield St; h, 816 South Ave, Wilkinsburg, Pittsburgh, Pa............... **Atlantic 4900-Ext. 202**

Cox, Roy Lipscomb (Jan. 1930) Dist. Mgr, Mining Dept, Jeffrey Mfg. Co, 600 Second Ave; h, 7047 Penn Ave, Pittsburgh, Pa.... **Court 2926**

Coxe, Edward Haviland (Jan. 1917) Salesman, Firefoam Sales Co, 30 Oakland Ave, Uniontown, Pa; h, 30 Oakland Ave, Uniontown, Pa. .... **Uniontown 1051-R**

Coxe, E. H., Jr. (**Associate**) (Nov. 1930) Dist. Mgr, General Cable Corp, 1814 Koppers Bldg; h, 565 East End Ave, Pittsburgh, Pa........ .... **Atlantic 0506**

Crafton, H. Herbert (**Associate Member**) (Dec. 1927) Mfg. Engr, H. H. Robertson Co, Ambridge, Pa; h, P. O. Box 131, Baden, Pa........ .... **Ambridge 375**

Craig, Albert Burchfield (Feb. 1925) Genl. Mgr, Chartiers Oil Co, 808 Columbia Bank Bldg; Pittsburgh, Pa; h, 234 Graham St, Sewickley, Pa.. **Court 3404**

Cramer, Robert Edward (Oct. 1923) Dist. Engr, American Steel & Wire Co, 830 Frick Bldg; h, 102 Catskill Ave, Brentwood Boro, Pittsburgh, Pa.................................... **Atlantic 5720**

Crane, J. B. (June 1921) Dist. Mgr, Combustion Engrg. Corp, 1606 First National Bank Bldg; h, 900 Berkshire Ave, Brookline, Pittsburgh, Pa . . . . **Atlantic 1511**

Crawbuck, John D. (**Associate Member**) (June 1927) Proprietor, John D. Crawbuck Co, 406 Empire Bldg; h, 1440 Severn St, Pittsburgh, Pa . . . . **Atlantic 6348**

Crawford, David Francis (June 1899) Consulting Engr; h, 5243 Ellsworth Ave, Pittsburgh, Pa . . . . **Mayflower 4360**

Crawford, Loyal F. (May 1914; Feb. 1924) Partner, Coal Mine Equipment Co, 2218 Farmers Bank Bldg, Pittsburgh, Pa . . . . **Atlantic 2700**

Crawford, Robert M. (Sept. 1927) Chemical & Industrial Engr, Private Practice, 48 Hyman Blvd, Buffalo, N. Y.

Crellin, Edward W. (May 1919) Engineer, 1550 San Pasqual St, Pasadena, Calif.

Criswell, John Russell (Sept 1929) Secretary, James Criswell Co, 1204 Keenan Bldg; h, 59 N. Fremont St, Bellevue, Pittsburgh, Pa. . . . . **Atlantic 5428**

Critchfield, Charles Lee (**Junior**) (June 1930) Instructor, University of Pittsburgh, 202 Thaw Hall; h, 311 Rochelle St, Mt. Oliver, Pittsburgh, Pa . . . . **Mayflower 3500**

Critchlow, Paul N. (March 1929) Patent Attorney, Brown & Critchlow, 1520-6 Farmers Bank Bldg, Pittsburgh, Pa; h, 231 Thorn St, Sewickley, Pa . . . . **Atlantic 2271**

Croak, John J. (Sept. 1922) Div. Engr, Bureau of Engineering, City of Pittsburgh, 443 City-County Bldg; h, 2636 Pioneer Ave, Brookline, Pittsburgh, Pa . . . . **Atlantic 3900-Ext. 238**

★**CROCKETT, ARTHUR E.** (**Silver Medal 1919**) (March 1909) Manager, Bureau of Instruction, Jones & Laughlin Steel Corp, 311 Ross St; h, 120 Ruskin Ave, Pittsburgh, Pa . . . . **Court 3240**

Cronemeyer, Henry C. (May 1903) Designer, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 181 College Ave, Beaver, Pa . . **Aliquippa 101**

Crooker, Ralph (March 1896) Acton, Mass.

Crouse, John L. (June 1918) Asst. to Transportation Sales Mgr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 401 S. Braddock Ave, Pittsburgh, Pa . . . . **Brandywine 1500-Ext. 913**

Culbertson, Albert Lewis (Oct. 1924) Manager, Furnace Div, The Rust Engineering Co, Koppers Bldg; h, 397 Jefferson Drive, Mt. Lebanon, Pittsburgh, Pa . . . . **Atlantic 8870**

Culler, A. A. (April 1923) Architectural and Structural Engr., Private Practice, 524 State Theatre Bldg, 335 Fifth Ave, Pittsburgh, Pa; h, 48 Highland Ave, Emsworth, Pa . . . . **Atlantic 5349**

Cummings, Alden Curry (March 1912) Electrical Engr, Carnegie Steel Co, Duquesne, Pa; h, 401 Catherine St, Duquesne, Pa... **Duquesne 5153**

Cundy, Oscar R. (Associate Member) (March 1916) Sales Engr, Sullivan Machinery Co, 518 Farmers Bank Bldg; h, 110 Marlin Drive, East, Mt. Lebanon, Pittsburgh, Pa........................ **Atlantic 2792**

Cunningham, David S. (Junior) (Jan. 1929) Draftsman, D. P. W, Bureau of Bridges, Div. of Design, Allegheny Co; h, 336 Breading Ave, Ben Avon, Pittsburgh, Pa.................. **Atlantic 4900-Ext. 44**

Curtin, Joseph McMeen (June 1929) Industrial Sales Mgr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 1515 Whitman St, Pittsburgh, Pa............................. **Brandywine 1500**

Cuthbert, William R., Jr. (April 1930) Assistant Engr, Pittsburgh Coal Co, 1012 Oliver Bldg; h, 41 Maplewood Ave, Crafton, Pittsburgh, Pa... **Atlantic 2181**

Cutler, Day Emerson (Feb. 1926) Compressor Specialist, General Electric Co, 1317 Oliver Bldg; h, 1520 S. Negley Ave, Pittsburgh, Pa. .... **Atlantic 6400**

Dake, Virgil H. (Feb. 1927) Supt. of Telephones, Philadelphia Co. and Affiliated Corps, 435 Sixth Ave; h, 931 Brookline Blvd, S. H, Pittsburgh, Pa.. **Grant 3200**

Dake, Walter M. (May 1926) Consulting Engr, In Charge Sales, Joy Mfg. Co, 505 15th St, Franklin, Pa............... **Franklin 306-7**

Dalbey, J. L. (March 1929) Engineer, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 559 12th Ave, New Brighton, Pa..... **Aliquippa 101**

Dalzell, C. W. (Associate) (April 1928) Engineer, Union Switch & Signal Co; h, 1015 S. Braddock Ave, Swissvale P. O. No. 18, Pittsburgh, Pa................................. **Penhurst 0880-Ext. 296**

Damrau, Edward A. (Associate) (Feb. 1925) Dist. Mgr, The Okonite Co. and The Okonite-Callender Cable Co, 1111 First National Bank Bldg; h, 1306 Milton Ave, Regent Square, Pittsburgh, Pa........ .... **Atlantic 1761**

Danahy, John (Associate Member) (Dec. 1928) Treas. and Genl. Mgr, Penn-Pitt Coal & Coke Co, Greensboro, Greene County, Pa.

Dandridge, Edmund Pendleton (May 1919) Dist. Mgr, Stephens-Adamson Mfg. Co, 1624 Oliver Bldg; h, 1326 Sheridan St, Pittsburgh, Pa. .... **Atlantic 0490**

★**DANFORTH, GEORGE HAGAR (Past President 1921)** (Jan. 1904) Contracting Engr, Jones & Laughlin Steel Corp, Third Ave & Ross St; h, 4750 Ellsworth Ave, Pittsburgh, Pa................ **Court 3240**

Daniel, Thomas L. (March 1924) Industrial Engr, Jacobson Engineering Co, 904 Plymouth Bldg, Minneapolis, Minn; h, 4657 Aldrich Ave, S, Minneapolis, Minn.

Daniels, Q. C. (April 1904) Mechanical Engr; h, 269 Main St, East Aurora, N. Y.

Dann, Alex. W. (**Associate Member**) (May 1921) Vice Pres. & Genl. Mgr, Keystone Sand & Supply Co, Dravo Bldg, 300 Penn Ave, Pittsburgh, Pa; h, 1207-A Besner Road, Glen Osborne, Sewickley, Pa. .... **Court 5400**

Daryman, Thomas A. (Jan. 1925) Salesman, Ingersoll Rand Co, 706 Chamber of Commerce Bldg; h, 106 Cleveland Ave, Avalon, Pittsburgh, Pa .... **Atlantic 9070**

Daubert, Charles W. (March 1921) Engineering Dept, American Sheet & Tin Plate Co, 1228 Frick Bldg; h, 407 Oakland Ave, Pittsburgh, Pa .... **Atlantic 1300**

Daum, Adam Edward (June 1904) President, Impervious Varnish Co, 2228 Koppers Bldg; h, 1355 Washington Road, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 0215**

Davies, John W. (April 1923) T. C. Allison Co, 812 Federal St, N. S; h, 1473 Alabama Ave, Dormont, Pittsburgh, Pa .... **Fairfax 0685**

Davies, Thomas P. (Nov. 1904) Chief Mech. Engr, Carnegie Steel Co, Duquesne Works; h, 913 Kennedy Ave, Duquesne, Pa .... **Duquesne 5153**

★**Davis, Charles Stratton** (May 1921) Consulting Engr, 903 Fulton Bldg, Pittsburgh, Pa; h, 306 Broad St, Sewickley, Pa .... **Atlantic 5923**

Davis, Clyde Ellsworth (Dec. 1923) Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 194 Ravine St, Aliquippa, Pa .... **Aliquippa 101**

Davis, Daniel E. (March 1923) Member of Firm, The J. N. Chester Engineers, 813 Clark Bldg, Pittsburgh, Pa; h, Osborne Lane, Glen Osborne, Pa .... **Atlantic 1140**

Davis, Harry Phillips (Dec. 1898; June 1924) Vice Pres, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 4917 Wallingford St, Pittsburgh, Pa .... **Brandywine 1500**

Davis, Jefferson (Dec. 1924) Dist. Engr, Detroit Graphite Co, 947 Oliver Bldg; h, Keystone Athletic Club, Pittsburgh, Pa .... **Atlantic 4330**

Davis, Ralph Emerson (March 1926) Consulting Engr, 1710 Union Bank Bldg; h, 5614 Northumberland St, Pittsburgh, Pa .... **Court 1776**

Davis, Ross Irwin (**Associate**) (March 1930) Asst. Genl. Mgr. of Sales, Hillman Coal & Coke Co, 2110 First National Bank Bldg; h, 3363 Francisco St, Pittsburgh, Pa .... **Atlantic 2620**

Davis, William Arthur (Jan. 1915) Mech. Engr, M. W. Kellogg Co, 225 Broadway, New York, N. Y; h, 23 Harvard St, East Orange, N. J.

DAVISON, ALLEN STEWART (Vice President) (June 1911) Vice Pres. and Treas, Davison Coke & Iron Co, 2119 Oliver Bldg; h, 210 Hawthorne St, Edgewood, Pittsburgh, Pa. . . . . **Atlantic 2290**

★**DAVISON, GEORGE S. (Past President 1898)** (Dec. 1880) President, Davison Coke & Iron Co, 2119 Oliver Bldg; h, Pittsburgh Athletic Association, Pittsburgh, Pa. . . . . **Atlantic 2290**

DeBerry, Sanford E. (Jan. 1930) Supt, McKeesport Coal & Coke Co, McKeesport, Pa; h, 4225 Walnut St, McKeesport, Pa. . . . . **McKeesport 3586**

Deckman, Edward J. (Dec. 1910) President, E. J. Deckman Co, Sales Engineers, 902 Oliver Bldg; h, 5671 Beacon St, Pittsburgh, Pa. . . . . **Atlantic 1843**

deFries, Walter (April 1924) Chief Engr, Wm. B. Pollock Co, 101 Andrews Ave, Youngstown, Ohio; h, 116 Ridgewood Drive, Youngstown, Ohio.

Deike, George Herman (Dec. 1924) Pres. & Treas, Mine Safety Appliances Co., Braddock Ave. & Thomas Blvd; h, 1028 Sheridan Ave, Pittsburgh, Pa. . . . . **Churchill 5900**

Demorest, George Myron (Associate Member) (Jan. 1925) Dist. Rep, Irving Iron Works Co, 241 Union Trust Bldg; h, Hampton Hall Apts, Dithridge St, Pittsburgh, Pa. . . . . **Atlantic 6238**

Dempler, George P. (April 1920) President, Geo. P. Dempler Co, 1206 House Bldg; h, 3318 Latonia Ave, Dormont, Pittsburgh, Pa. . . . . **Court 0610**

Denigan, Edward P. (Associate Member) (March 1927) Salesman, Pittsburgh-Des Moines Steel Co, Neville Island; h, Lebanon Hall, Mt. Lebanon, Pittsburgh, Pa. . . . . **Federal 3000**

Dent, John Adlum (Nov. 1928) Professor of Mechanical Engineering, University of Pittsburgh, 102 Thaw Hall; h, 3415 Iowa St, Pittsburgh, Pa. . . . . **Mayflower 3500**

Desch, John Leo (Feb. 1927) 4 Commonwealth Ave, Boston, Mass.

Dethloff, William Louis (Nov. 1923) Pres. & Genl. Mgr, American Nickel Corp, Hyde, Clearfield Co, Pa; h, 122 Weaver St, Clearfield, Pa.

Deuel, Harry Austin (Dec. 1928) Chief Industrial Engr, Jones & Laughlin Steel Corp, S. S. Works; h, Schenley Apts, Pittsburgh, Pa. . . . . **Hemlock 0401**

de Vou, James L. (May 1921) Manager, Central District, Erecting Dept, American Bridge Co, 1525 Frick Bldg; h, 5475 Bartlett St, Pittsburgh, Pa. . . . . **Atlantic 4300**

Dibble, Robert Horace (May 1926) Metallurgical Engr, American Sheet & Tin Plate Co, 1302 Frick Bldg, P. O. Box 62; h, 7711 Brashear St, Wilkinsburg, Pittsburgh, Pa.......................... **Atlantic 1300**

Dickerson, James Howard (Sept. 1910) Proposal Engr, American Coal Cleaning Corp, Welch, West Va; h, P. O. Box 464, Welch, West Va.

★**Diehl, Ambrose Nevin** (June 1901) Vice Pres, U. S. Steel Corp, Room 1917, 71 Broadway, New York, N. Y.

Diehl, David H. (Dec. 1925) Supt. of Construction, James L. Stuart, 338 East North Ave; h, 909 Bayridge Ave, Pittsburgh, Pa..**Fairfax 3126**

★**Diescher, Alfred J.** (Sept. 1902) President, Emerald Oil Co, State Bank Bldg, Winfield, Kansas; h, Lagonda Hotel, Winfield, Kansas.

Diescher, Samuel Endres (Feb. 1903) Member of Firm, S. Diescher & Sons, Farmers Bank Bldg; h, 724 S. Negley Ave, Pittsburgh, Pa. ....**Atlantic 4975**

★**Dignan, George Edward** (April 1921) Chief Engr, Davison Coke & Iron Co, Neville Island, Pittsburgh, Pa; h, 27 Priscilla Lane, Rosslyn Farms, Carnegie, Pa..............................**Federal 3700**

Dilley, James Max (April 1924) Pgh. Rep, Bessemer Cement Corp, 925 Frick Bldg, Pittsburgh, Pa; h, 320 Frederick Ave, Sewickley, Pa. ....**Atlantic 0610**

Dillon, Sydney (March 1917) Asst. to Vice Pres, Carnegie Steel Co. 1216 Carnegie Bldg, Pittsburgh, Pa..............**Atlantic 5100-Ext. 241**

Dinkey, Alva Clymer (Nov. 1897) President, The Midvale Co, Nicetown, Philadelphia, Pa; h, 314 Kent Road, Wynnewood, Pa.

Dinneen, William Thomas (Associate Member) (Oct. 1926) Pres. & Treas, William T. Dinneen Construction Co, Goodridge St. Lynn, Mass; h, 20 Buchannan Circle, Lynn, Mass.

Dolan, Albert Vincent (Nov. 1915) Engr. of Erection, Fort Pitt Bridge Works, 2026 Oliver Bldg; h, 107 Steuben St, Crafton, Pittsburgh, Pa..**Atlantic 0654**

Donald, John S. (Junior) (June 1925) Sales Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 115 Delafield Ave, Aspinwall, Pittsburgh, Pa....................................**Sterling 2700**

Donaldson, Joseph T. (Oct. 1903) Engineer, Riter Conley Works, McClintic Marshall Co, Pittsburgh, Pa; h, 148 Irwin Ave, Ben Avon, Pittsburgh, Pa....................................**Atlantic 2562**

Donaldson, Robert R., Jr. (Sept. 1921) Chief Engr, Service Dept, Hagan Corp, Bowman Bldg; h, 443 Cascade Road, Forest Hills, Wilkinsburg, Pittsburgh, Pa...............................**Court 4724**

Donnan, David M. (Sept. 1921) Pres. & Genl. Mgr, Electrical Engrg. & Mfg. Co, 907 Penn Ave; h, 49 Briar Cliff Road, Ben Avon Heights, Pittsburgh, Pa .... **Grant 6693**

Dornbush, Charles C. (April 1915) Sales Engr, Jones & Laughlin Steel Corp, Third & Ross Sts; h, 551 Highland Place, Bellevue, Pittsburgh, Pa .... **Court 3240**

Dorsey, Charles H. (May 1925) Treasurer, The R. G. Johnson Co, 1110 House Bldg, Pittsburgh, Pa; h, 36 Huffman Ave, Washington, Pa .... **Court 3753**

Dougall, C. R., Jr. (**Junior**) (Oct. 1928) Draftsman, The John N. Chester Engineers, 813 Clark Bldg; h, 745 Glenn Ave, Wilkinsburg, Pittsburgh, Pa .... **Atlantic 1140**

Dowling, Eugene (June 1928) Industrial Sales Mgr, Johns-Manville Corp, 6300 Euclid Ave, Cleveland, Ohio; h, 3327 Kenmore Road, Cleveland, Ohio.

Down, S. G. (March 1924) Vice Pres, Westinghouse Air Brake Co, Wilmerding, Pa; h, 204 Hawthorne St, Edgewood, Pittsburgh, Pa .... **Brandywine 1490**

Downer, Charles Boddie (Dec. 1926) Engineer, Overhead Lines Dept, West Penn Power Co, 14 Wood St; h, 2703 Norwood Ave, N. S, Pittsburgh, Pa .... **Court 4106**

★**Drake, Chester Francis** (Dec. 1904) Supt. Filtration Div, Bureau of Water, City of Pittsburgh, Filtration Plant, Aspinwall, Pittsburgh, Pa. .... **Sterling 0147**

★**Dravo, Francis Rouand** (Dec. 1904) President, Dravo Contracting Co, Dravo Bldg, 302 Penn Ave, Pittsburgh, Pa; h, East Drive, Sewickley, Pa .... **Federal 2600**

Drylie, William A. (April 1925) Supt. Steam Dept, Edgar Thomson Works, Carnegie Steel Co, Braddock, Pa; h, 7316 Schoyer Ave, Swissvale, Pittsburgh, Pa .... **Brandywine 2590-Ext. 23**

★**Duckham, Albert Edward** (March 1892) Consulting Civil Engr, 64 Vandergrift Bldg; h, 246 S. Aiken Ave, Pittsburgh, Pa .... **Court 1926**

★**Duckworth, Thomas** (Feb. 1910) Erection Engr. & Supt. Honolulu Iron Works Co, United Sugar Companies of Mexico, Los Mochis, Sinaloa, Mexico; h, Birch & Railroad Aves, Hempstead, New York, N. Y.

Duden, Emil Gustav (April 1913) Chief Engr, Water Purifying Dept, Wm. B. Scaife & Sons Co, Oakmont, Pa; h, Fourth St, Oakmont, Pa. .... **Oakmont 9**

Duff, J. Milton (May 1928) Consulting Engr, Phillips Mine & Mill Supply Co, 2227 Jane St; h, 211 The Boulevard, Mt. Oliver Station, Pittsburgh, Pa .... **Hemlock 0130**

Duff, Levi Bird (Oct. 1913) Consulting Engr, Samuel E. Duff-Levi Bird Duff, Consulting Engineers, 712 Magee Bldg; h, 225 Dickson Ave, Ben Avon, Pittsburgh, Pa .... **Court 3542**

★**DUFF, SAMUEL ECKERBERGER (Past President 1916)** (Oct. 1908) Consulting Engr, Samuel E. Duff-Levi Bird Duff, Consulting Engineers, 712 Magee Bldg; h, 7177 Brighton Road, Ben Avon, Pittsburgh, Pa .... **Court 3542**

Dunbar, Frank B. (Oct. 1927) Genl. Supt. Mather Collieries, Pickands, Mather & Co, Mather, Greene County, Pa.

Dunham, Byron W. (June 1921) Chief Engr, Edgewater Steel Co, P. O. Box 249, Pittsburgh, Pa; h, 434 Ninth St, Oakmont, Pa .... **Oakmont 280**

Dunn, H. Earl (Dec. 1924) Metallurgical Asst. to Vice Pres. Vanadium Corp. of America, Bridgeville, Pa; h, 19 N. Emily St, Crafton Sta, Pittsburgh, Pa .... **Carnegie 1186**

Dunn, J. Jay (Feb. 1917) Asst. to Vice Pres, National Tube Co, Frick Bldg, Pittsburgh, Pa; h, 200 Fountain St., Ellwood City, Pa. **Atlantic 2500**

Dunnells, Clifford George (March 1922) Member of Firm, Hunting, Davis and Dunnells, 1150 Century Bldg; h, 141 Riverview Ave, N. S, Pittsburgh, Pa .... **Atlantic 6941**

Dunsford, Jan Rubidge (Nov. 1916) President, Union Steel Casting Co, 62nd & Butler Sts, Pittsburgh, Pa; h, 310 Quaker Road, Edgeworth, Pa .... **Fisk 0456**

Dwelle, Edwin R. (Associate Member) (March 1929) Sales Engr, Barney Machinery Co, 2410 Koppers Bldg; h, 123 Montclair Ave, West View, Pittsburgh, Pa .... **Atlantic 4116**

DYCHE, HOWARD EDWARD (Chairman Electrical Section) (Sept. 1926) Professor, Electrical Engineering, University of Pittsburgh; h, 317 South Ave, Wilkinsburg, Pittsburgh, Pa .... **Mayflower 3500**

Dykeman, Howard E. (Oct. 1927) Designing Engr, Arthur G. McKee & Co, 2400 Euclid Ave, Cleveland, Ohio; h, 3307 Washington Blvd, Cleveland Heights, Cleveland, Ohio.

Dym, Emanuel (Associate) (May 1924) President, Pittsburgh State Bank. 507 Fifth Ave; h, 5415 Hobart St, Pittsburgh, Pa .... **Atlantic 8686**

Eastman, Horace Merriam (June 1911) Sales Engr, Jones & Laughlin Steel Corp, 165 Broadway, New York; N. Y; h, 56 S. Walnut St, East Orange, N. J.

Eastwood, Sidney K. (May 1921) Erecting Dept, American Bridge Co, 1528 Frick Bldg; h, Elberon Apts, 301 S. Winebiddle Ave, Pittsburgh, Pa .... **Atlantic 4300**

Eaton, Henry T. (May 1923) Mech. Draftsman, Oliver Iron & Steel Corp, S. 10th & Muriel Sts, S. S; h, 910 Ditzler St, Pittsburgh, Pa.... ....**Court 0842**

★**Eavenson, Howard N.** (Nov. 1920) President, Eavenson, Alford & Hicks, 1300 Union Trust Bldg; h, 4411 Bayard St, Pittsburgh, Pa...... ....**Atlantic 3939**

Ebberts, Alfred R. (March 1927) Engineer of Tests, Allegheny County, 519 Smithfield St; h, 1206 Heberton St, Pittsburgh, Pa.......... ....**Atlantic 4900-Ext. 141**

Ebersole, F. Leslie (April 1926) Master Mechanic, Park Works, Crucible Steel Co. of America, 30th & Smallman Sts; h, General Brodhead Hotel, Beaver Falls, Pa............................**Atlantic 8620**

Eckels, Charles E. (**Junior**) (Nov. 1927) Technical Employee, American Telephone & Telegraph Co, 302 Smithfield St; h, 1108 Gladys Ave, Pittsburgh, Pa.............................**Official 0050-Ext. 21**

★**Eckels, Samuel** (May 1925) Chief Engr, Pennsylvania Dept. of Highways, Harrisburg, Pa; h, 925 N. Front St, Harrisburg, Pa.

★**EDGAR, LOUIS C.** (**President**) (Dec. 1915) Chief Engr, Edgar Thomson Works, Carnegie Steel Co, Braddock, Pa; h, 2022 Hampton Ave, Swissvale, Pittsburgh, Pa...............**Brandywine 2590-Ext. 16**

Edgar, William Claney (May 1921) Wm. C. Edgar Co, 1815 Oliver Bldg; h, 3546 Campus St, Pittsburgh, Pa.................**Atlantic 0419**

Edmonds, John Franklin, Jr. (**Associate Member**) (May 1930) Cost Clerk, Duquesne Light Co, 6119 Penn Ave; h, 1445 Greystone Drive, Pittsburgh, Pa.......................................**Hiland 6700**

Edstrom, Eric Herbert (**Associate Member**) (Feb. 1929) E. W. Bliss Co, Salem, Ohio.

Edwards, Edward Tudor (Nov. 1913) Pres. & Mgr, Vanadium Alloys Steel Co, Latrobe, Pa; h, Latrobe, Pa.

Edwards, Vere Buckingham (Oct. 1913) Vice Pres. & Chief Engr, The Dravo Contracting Co, Dravo Bldg, 300 Penn Ave, Pittsburgh, Pa; h, R. D. No. 2, Coraopolis, Pa.................**Federal 2600**

Ehmann, Roy Leon (Sept. 1923) Dist. Mgr, The Superheater Co, 923 Union Trust Bldg; h, 2966 Espy Ave, Dormont, Pittsburgh, Pa. ....**Atlantic 3799**

Ehrhart, R. N. (Dec. 1928) Consulting Engr, 1 Fifth Ave, New York, N. Y.

Eichleay, John P. (Feb. 1917) President, John Eichleay, Jr. Co, 45 S. 20th St; h, 421 Bailey Ave, Pittsburgh, Pa..............**Hemlock 0420**

Eichleay, Roy Oliver (Dec. 1928) Vice Pres, John Eichleay Jr. Co. and President, Pittsburgh Thermoline Co, 45 S. 20th St; h, 2717 Glenmore Ave, Dormont, Pittsburgh, Pa.............. **Hemlock 0420**

Eisenbeis, Walter Herman (March 1916) Asst. Sales Mgr, Union Steel Casting Co, 62nd & Butler Sts; h, Alger St. & Beechwood Blvd, Pittsburgh, Pa.................................... **Fisk 0456**

Eissler, Robert Frederick(Associate) (Nov. 1927) Dist. Mgr, Chicago Pneumatic Tool Co, 1053 Century Bldg, Pittsburgh, Pa; h, Sharon Road, Coraopolis Heights, Coraopolis, Pa............ **Atlantic 4286**

Elliott, Byron K. (Feb. 1903) Pres. & Treas, B. K. Elliott Co, 126 Sixth St, Pittsburgh, Pa; h, 33 Castle Shannon Road, Mt. Lebanon, Pittsburgh, Pa.................................. **Grant 3660**

Elliott, Robert T. (Oct. 1924) Field Engr, The Koppers Construction Co, c/o Seaboard By-Product Coke Co, Kearny, N. J; h, 17 Webester Place, East Orange, N. J.

Elliott, William S. (Nov. 1901) President, The Elliott Co, 222 Frick Bldg; h, Woodland Road, Pittsburgh, Pa.................. **Atlantic 5000**

Ellis, Albert Ralph (April 1924) Vice Pres, Pittsburgh Testing Laboratory, Stevenson & Locust Sts, P. O. Box 1115; h, 6963 Edgerton Ave, Pittsburgh, Pa.................................. **Grant 3860**

Ellman, Fred (Associate Member) (Oct. 1924) Sales Engr, M. H. Detrick Co, 712-13 Empire Bldg; h, 5846 Alderson St, Pittsburgh, Pa. .... **Atlantic 1477**

★**Ellman, Louis** (Dec. 1923) Dist. Mgr, M. H. Detrick Co, 712-13 Empire Bldg; h, 5427 Hobart St, Pittsburgh, Pa............. **Atlantic 1477**

Ellsworth, Walter Erwin (June 1929) Dist. Mgr, Maxon Premix Burner Co, 414 Bessemer Bldg; h, 222 Grant Ave, Bellevue, Pittsburgh, Pa.. **Grant 1941**

Elshoff, R. H. (Associate) (Jan. 1925) Sales Engr, Vacuum Oil Co, Provident Bank Bldg, Vine & 17th Sts, Cincinnati, Ohio; h, 2806 Middletown Road, Crafton, Pittsburgh, Pa.

Elwell, G. Randolph (May 1926) Construction Engr, Pittsburgh Works, Standard Sanitary Mfg. Co, 2801 Preble Ave; h, 3945 Grenet St, N. S, Pittsburgh, Pa............................. **Linden 6070**

Ely, Fred W. (June 1930) Chief Designing Engr, Hydraulic Dept, Aluminum Co. of America, 2400 Oliver Bldg, Pittsburgh, Pa; h, 1425 Park Blvd, S. H, Pittsburgh, Pa......................... **Atlantic 4545**

★**Ely, Sumner B.** (Sept. 1900) Asst. Prof. of Commercial Engineering, Carnegie Inst. of Technology; h, 5122 Pembroke Place, Pittsburgh, Pa.. **Mayflower 2600**

Endsley, Louis E. (Dec. 1924) Consulting Engineer; h, 516 East End Ave, Pittsburgh, Pa . . . . **Churchill 3846**

Engel, Arthur William (Dec. 1921) Structural Steel Designer, American Bridge Co, 1420 Frick Bldg, Pittsburgh, Pa; h, 628 Mulberry St, Sewickley, Pa . . . . **Atlantic 4300**

Enzian, Charles (April 1929) Chief Engr, The Consolidation Coal Co, Watson Bldg, Fairmont, West Va; h, 828 Locust Ave, Fairmont, West Va.

Espenschade, Park William (Junior) (Dec. 1927) Rwy. Equipment Engr, Heisler Locomotive Works, 16th & Hickory Sts, Erie, Pa; h, c/o Y. M. C. A, Erie, Pa.

★**Estep, Thomas G.** (Oct. 1927) Professor, Mechanical Engineering, Carnegie Inst. of Technology; h, 949 S. Braddock Ave, Wilkinsburg, Pittsburgh, Pa . . . . **Mayflower 2600**

Etheridge, Harry (March 1926) Vice Pres. & Genl. Mgr, Pittsburgh, Butler & Harmony Cons. Rwy. & Power Co, Harmony, Pa; h, Zelienople, Pa.

Evans, Norman H. (Student Junior) (Dec. 1927) Junior Patent Examiner, U. S. Patent Office, Washington, D. C; h, Apt. 602, 2025 I St, N. W, Washington, D. C.

Evans, Thomas Raymond (March 1919) President, Diamond Alkali Co, Koppers Bldg; h, 1129 Beechwood Blvd, Pittsburgh, Pa . . **Grant 7500**

Evarts, Ralph E. (Associate Member) (Dec. 1928) Research Engr, Pittsburgh Equitable Meter Co, 400 Lexington Ave; h, 723 Whitney Ave, Wilkinsburg, Pittsburgh, Pa . . . . **Churchill 8400**

Everhard, Edgar Philip (April 1917; Dec. 1925) Chief Engr, Freyn Engineering Co, 310 S. Michigan Ave, Chicago, Ill; h, 206 Ulm Place, Hinsdale, Ill.

Ewald, Harry W. (Associate) (March 1926) Asst. to Vice Pres. In Charge Sales Duquesne Light Co, 435 Sixth Ave; h, 1548 Tolma Ave, Dormont, Pittsburgh, Pa . . . . **Grant 4300-Ext. 421**

Ewald, Robert F. (Associate Member) (June 1930) Hydraulic Engr, Aluminum Co. of America, 2400 Oliver Bldg; h, 447 Avon Drive, Mt. Lebanon, Pittsburgh, Pa . . . . **Atlantic 4545**

Ewalt, Dwight Sapp (Oct. 1927) Sales Engr, The Rust Engineering Co, Koppers Bldg; h, 219 Mabrick Ave, Mt. Lebanon, Pittsburgh, Pa . . . . **Atlantic 8870**

Faris, Jacob M. (Jan. 1912) Supt, Mech. & Elec. Depts, Youngstown Sheet & Tube Co, Youngstown, Ohio; h, 1711 Fifth Ave, Youngstown, Ohio.

Farnham, Thaddeus L. (Dec. 1924) Vice Pres, W. M. McKee, Inc, 436 Oliver Bldg; h, 548 Neville St, Pittsburgh, Pa....... **Atlantic 4658**

Fawcett, William H. (Associate) (March 1930) Asst. Cashier, First National Bank at Pittsburgh, Wood & Fifth Ave; h, 26 Mt. Lebanon Blvd, S. H, Pittsburgh, Pa.......................... **Atlantic 5630**

★**Fear, Thomas George** (Sept. 1923) Genl. Mgr. of Operations, Consolidation Coal Co, Inc, Watson Bldg, Fairmont, West Va; h, 717 Fairmont Ave, Fairmont, West Va.

Fechheimer, Carl J. (April 1922) Section Engr, Elec. Dev. Power Engrg. Dept, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 5420 Plainfield St, Pittsburgh, Pa.............. **Brandywine 1500**

Fendner, Willard J. (June 1919) Mech. Engr, Schaefer Equipment Co, 2710 Koppers Bldg; h, 352 Stratford Ave, Pittsburgh, Pa.. **Atlantic 0984**

★**Ferguson, John Ashley** (Dec. 1907; Jan. 1909) John A. Ferguson Engineers, 720 Empire Bldg; h, 1419 N. Euclid Ave, Pittsburgh, Pa.. **Atlantic 2371**

Ferguson, John Marshall (April 1916) President, Ferguson Gates Engineering Co, Allen Bldg, P. O. Box 669, Beckley, Raleigh Co, West Va; h, North Kanawha St, Beckley, West Va.

Ferrabee, Francis Gilbert (Associate Member) (May 1930) Sales Engr, Ingersoll Rand Co, 706 Chamber of Commerce Bldg; h, 5552 Beacon St, Pittsburgh, Pa................................ **Atlantic 9070**

Ferrara, George Peter (July 1912) Struct. Engr, The Koppers Construction Co, Koppers Bldg; h, 1520 Murray Ave, Pittsburgh, Pa. .... **Atlantic 6240**

Ferree, Jay W. (March 1930) Chief Engr, William M. Bailey Co, 702 Magee Bldg; h, 1002 S. Braddock Ave, Pittsburgh, Pa.. **Court 2041**

Fetherling, Herschel G. (Associate) (Dec. 1924) President, Fetherling Sales Co, 604 Chamber of Commerce Bldg; h, 826 Gearing Ave, Pittsburgh, Pa................................ **Atlantic 8741**

Feucht, George Charles (Sept. 1918) Structural Engr, Jones & Laughlin Steel Corp, 311 Ross St; h, 432 Orchard Place, Mt. Oliver Sta, Pittsburgh, Pa.................................. **Court 3240**

★**Fieldner, Arno C.** (April 1919) Chief Engr, Experiment Stations Div, U. S. Bureau of Mines, 17th and F Sts, Washington, D. C; h, 4739 13th St, N. W, Washington, D. C.

Figee, William F. (Associate Member) (Feb. 1925) Sales Engr, Rush Machinery Co, 3565 Bigelow Blvd; h, 743 Bayridge Ave, Brookline, Pittsburgh, Pa................................ **Schenley 7600**

Finley, Charles A. (April 1903; Sept. 1910) Chairman, Traction Conference Board, First National Bank Bldg; h, 814 Washington Blvd, Pittsburgh, Pa.. **Atlantic 2173**

Finley, Norval Howard (April 1903) Chemical Engr, Metropolitan Refining Co. of New York, 921 Empire Bldg; h, 7229 Hermitage St, Pittsburgh, Pa.. **Atlantic 6716**

Firth, L. Gerald (March 1924) Genl. Mgr, Firth-Sterling Steel Co, McKeesport, Pa; h, 5575 Northumberland St, Pittsburgh, Pa.......... .... **McKeesport 4181**

Fisher, Gordon (Nov. 1927) President, Spang-Chalfant & Co, Inc, Clark Bldg; h, 4 Colonial Place, Pittsburgh, Pa........... **Atlantic 9230**

Fitch, George Carroll (April 1928) Chief Draftsman, Blum, Weldin & Co, Bakewell Bldg, 417 Grant St; h, 1822 Pioneer Ave, Pittsburgh, Pa.. **Court 4997**

Fitzgerald, John Morton (Dec. 1911) Assistant to Chairman, Committee on Public Relations of the Eastern Railroads, 143 Liberty St, New York, N. Y; h, 91 Central Park, West, New York, N. Y.

★**Fitzgerald, Thomas** (Dec. 1920) Vice Pres, Pittsburgh Railways Co, 435 Sixth Ave; h, 5216 Fifth Ave, Pittsburgh, Pa.. **Grant 7450-Ext. 125**

★**FLANAGAN, WALTER N.** (**Chairman Mechanical Section**) (Oct. 1926) Special Engr, Carnegie Steel Co, 1500 Carnegie Bldg; h, 3248 Eastmont Ave, S. H, Pittsburgh, Pa............... **Atlantic 5100**

Flippen, John Philip (Jan. 1927) Dist. Mgr, Farrel Fdry. & Machine Co, and C. H. Wheeler Mfg. Co, Oliver Bldg; h, 1237 Murdock St, Pittsburgh, Pa.................................. **Atlantic 3697**

Flynn, Francis Edward (**Junior**) (Dec. 1928) Asst. Supervisor, Pennsylvania R. R. Co, Trafford, Pa; h, First St, Trafford, Pa **Pitcairn 200-Ext. 437**

Focer, Percy C. (Dec. 1930) Engineer, The Rust Engineering Co, 2600 Koppers Bldg; h, 7916 Inglenook Place, Pittsburgh, Pa **Atlantic 8870**

Fohl, Charles Taylor (**Junior**) (Sept. 1921) Engineer, Truscon Steel Co, Miami, Florida.

Fohl, Edward Zinn (**Junior**) (April 1928) Asst. Engr, Bell Telephone Co, of Penna, 416 Seventh Ave; h, 7405 Penfield Court, Pittsburgh, Pa.................................... **Official 0050-Ext. 274**

★**FOHL, WILLIAM EDWARD** (**Past President 1926**) (Jan. 1897) Consulting Mining Engineer, 1209 House Bldg; h, 322 S. Lang Ave., Pittsburgh, Pa...................................... **Court 2974**

★**Forsberg, Rudolf Percy** (May 1921) Principal Asst. Engr, Pittsburgh & Lake Erie R. R. Co, P. & L. E. Terminal Bldg, Pittsburgh, Pa; h, Oliver Road, Emsworth, Pa....................... **Court 3201**

Forsstrom, William K. (Oct. 1901) Chief Engr, Wisconsin Steel Works, S. Chicago, Ill; h, Gladstone Hotel, 6200 Kenwood Ave, Chicago, Ill.

Fortune, J. Robert (Nov. 1905) Manager, Heating Div, Wickes Boiler Co, Saginaw, Mich; h, Bancroft Hotel, Saginaw, Mich.

Foss, Feodore F. (Jan. 1925) Asst. to Pres, Wheeling Steel Corp, 622 Wheeling Steel Corp. Bldg, Wheeling, West Va; h, 111 Bae Mar Place, Wheeling, West Va.

★**Foster, Samuel D.** (Feb. 1911) Consulting Engineer, 1704 Arrott Bldg; h, 5852 Marlborough St, Pittsburgh, Pa. . . . . **Court 2106**

Foster, William Barclay (Associate) (May 1924) Agent, Travelers Insurance Co, St. Paul Fire & Marine Insurance Co, 524 Chamber of Commerce Bldg; h, 1251 Murdock St, Pittsburgh, Pa. . . . **Atlantic 9700**

Fowler, William E., Jr. (March 1926) Chief Engr, Montour Railroad Co, 1711 State St, Coraopolis, Pa; h, Poland, Ohio. . . **Coraopolis 72**

Fownes, William Clark, Jr. (Sept. 1924) Treasurer, Standard Seamless Tube Co, 313 Sixth Ave; h, 819 N. Highland Ave, Pittsburgh, Pa. . . . . **Atlantic 9230**

Fox, Cyril A. (Feb. 1929) Owner and Manager, Fox Grinder Co, Oliver Bldg; h, 515 Ninth St, Oakmont, Pa. . . . . **Atlantic 1504**

Fox, Charles Louis (Feb. 1903) Asst. Supt, Pennsylvania Water Co, 712 South Ave, Wilkinsburg, Pittsburgh, Pa; h, 375 West Penn Place, Pittsburgh, Pa. . . . . **Penhurst 0107**

Fox, John Herbert (Feb. 1911) Executive Engr, Pittsburgh Plate Glass Co, 2300 Grant Bldg; h, The University Club, Pittsburgh, Pa. . . . . **Atlantic 5600**

Francies, William Hugh (Jan. 1907) Div. Supt, Allegheny County, 519 Smithfield St, Pittsburgh, Pa; h, 32 Center Ave, Emsworth, Pittsburgh, Pa. . . . . **Atlantic 4900-Ext. 54**

Francis, Charles B. (Feb. 1928) Director, Bureau of Technical Instruction, Carnegie Steel Co, 214 Carnegie Bldg; h, 815 Bellaire Ave, S. H., Pittsburgh, Pa. . . . . **Atlantic 5100-Ext. 316**

Frank, Harry H. (Associate Member) (Dec. 1924) Manufacturers' Representative, 207 Fulton Bldg; h, 2510 Shady Ave, Pittsburgh, Pa. . . . . **Atlantic 9730**

Frank, Robert J. (Jan. 1928) Vice Pres. Charge of Sales, Copperweld Steel Co, Glassport, Pa; h, 1336 Inverness Ave, Pittsburgh, Pa. . . . . **Brandywine 1320**

Frank, William Klee (Sept. 1913) Vice Pres, Copperweld Steel Co, Glassport, Pa; h, 5535 Aylesboro Ave, Pittsburgh, Pa. . **Brandywine 1320**

★**Frauenheim, Aloysius M.** (**Associate Member**) (Dec. 1927) Sales Engr, Standard Auto-Tite Joints Co, 916 Forbes St; h, 110 Bigham St, Pittsburgh, Pa. . . . . **Atlantic 6615**

Frazer, C. E. (Dec. 1927) President, Simplex Engineering Co, Washington Trust Bldg, Washington, Pa; h, 417 E. Bean St, Washington, Pa.

Frease, John B. (April 1921) Practising Engineer, 510-11 Shields Bldg, 822 Wood St, Wilkinsburg; h, 435 Franklin Ave, Wilkinsburg, Pittsburgh, Pa. . . . . **Churchill 3628**

Frederick, Paul (Oct. 1928) Sales Engr, General Electric Co, 1309 Oliver Bldg; h, Osborne Lane, Sewickley, Pa . . . . **Atlantic 6400**

Freeman, Andrew Y. (Sept. 1925) Junior Design Engr, Allegheny County, 519 Smithfield St, Room 204; h, 2815 Voelkel Ave, Dormont, Pittsburgh, Pa . . . . **Atlantic 4900-Ext. 44**

Freeman, Henry Raymond, Jr. (**Associate**) (Jan. 1929) Manager, Tubular Dept, National Supply Co, 319 Frick Bldg; h, 23 Linden Place, Sewickley, Pa. . . . . **Grant 2328**

Freeman, Perry John (March 1924) Chief Engr, Bureau Tests, Dept. Public Works, Allegheny County, 519 Smithfield St; h, 264 Orchard Drive, Mt. Lebanon, Pittsburgh, Pa . . . . **Atlantic 4900-Ext. 141**

Freund, Jacob deS. (June 1911) Secy. & Genl. Mgr, American Cement Tile Mfg. Co, 826 Oliver Bldg; h, 1088 Shady Ave, Pittsburgh, Pa . . . . **Atlantic 2480**

Friederici, Max (Nov. 1921) Chief Draftsman, Weirton Steel Co, Steubenville, Ohio; h, 304 Belleview Blvd, Steubenville, Ohio.

Frohman, E. D. (April 1896; March 1915) Vice Pres, The S. Obermayer Co, 33rd & A.V.R.R.; h, 245 Melwood St, Loutellus Apts, Pittsburgh, Pa. . . . . **Atlantic 6547**

Frohrieb, Louis C. (July 1910) Federal Engineering Co, 1420 Investment Bldg, 239 Fourth Ave; h, 1107 Peermont Ave, Dormont, Pittsburgh, Pa . . . . **Court 2672**

Frys, D. W., Jr. (**Junior**) (Nov. 1928) Mining Engr, Industrial Dept, Equitable Gas Co, 435 Sixth Ave; h, Jane Apts, Greendale Ave, Edgewood, Pittsburgh, Pa. . . . . **Grant 7600-Ext. 668**

Fuhs, William F. (Oct. 1925) Secretary, Pihl & Miller, Inc, 637 Wabash Bldg; h, 1214 Biltmore Ave, Dormont, Pittsburgh, Pa. . **Court 1670**

★**Fuller, Samuel L.** (April 1910; Jan. 1922) Vice Pres, John F. Casey Co, P. O. Box 1753; h, 1159 King Ave, Pittsburgh, Pa. . . . **Sterling 1400**

Fullman, James Miller Grant (Dec. 1901) Genl. Designing Engr, National Electric Products Corp, 14th St, Ambridge, Pa; h, 904 Beaver St, Sewickley, Pa . . . . **Ambridge 15**

★**Fulton, James Stewart** (June 1923) Special Rep, Ingersoll-Rand Co, 706 Chamber of Commerce Bldg, Pittsburgh, Pa; h, 431 Maple Lane, Edgeworth, Shields P. O., Pa........................**Atlantic 9070**

Fulton, Luther D. (March 1930) Supt, The Penzoil Co, Rouseville, Pa; h, 402 W. Main St, Titusville, Pa.

Fusca, Emil A. (Jan. 1927) Draftsman, Pittsburgh Plate Glass Co, Grant Bldg; h, P. O. Box 174, Perrysville, Pa..............**Atlantic 5600**

★**Gadsby, G. M.** (March 1924) President, Utah Power & Light Co, Kearns Bldg, Salt Lake City, Utah; h, 808 E. S. Temple St, Salt Lake City, Utah.

Gaines, Edward C. (April 1916) Engineer, Mead Morrison Mfg. Co, Monadnock Block, Chicago, Ill; h, 5046 Winthrop Ave, Chicago, Ill.

Gallinger, Walter N. (Dec. 1922) Mining Engineer, 344 Semple St, Pittsburgh, Pa.

Gare, Marshall Stearns (Dec. 1927) Engineer, Hagan Corp, 502 Bowman Bldg; h, 6947 McPherson Blvd, Pittsburgh, Pa........**Court 4724**

Garratt, Frank (Feb. 1912; Oct. 1925) Metallurgical Engr, Universal Steel Co, Bridgeville, Pa; h, 271 Jefferson Drive, S. H, Pittsburgh, Pa. ....**Bridgeville 34**

Garretson, Forrest Dorsey (Jan. 1930) Chief Inspector, Dept. of Highways, State of Pennsylvania, 1329 Electric Ave, East Pittsburgh, Pa; h, 220 Delaware Ave, East McKeesport, Pa............**Valley 2416**

★**GASCHE, FERDINAND GUY (Silver Medal 1913)** (Feb. 1912) Combustion Engr, Bethlehem Steel Co, Lackawanna Plant, Lackawanna, N. Y; h, 228 Anderson Place, Hamburg, N. Y.

Gass, Karl William (April 1920) Asst. Mgr, Stephens-Adamson Mfg. Co, 1624 Oliver Bldg; h, 5512 Beverly Place, Pittsburgh, Pa **Atlantic 0490**

Gealy, E. J. (Associate) (Feb. 1929) Electrical Engr, Pittsburgh Coal Co, Oliver Bldg; h, 2574 Beechwood Blvd, Pittsburgh, Pa..**Atlantic 2181**

Geeseman, Delbert B. (April 1922) Asst. Mgr, Standard Tin Plate Co, Canonsburg, Pa; h, 207 W. Pike St, Houston, Pa...**Canonsburg 65**

Gerwig, Frederick Henry Nicholas (Feb. 1902) Mill Supt, Carnegie Steel Co, Edgar Thomson Works; h, 901 Kirkpatrick Ave, Braddock, Pa...**Brandywine 2590**

Gibbs, C. Willard (Jan. 1930) Genl. Mgr, Harwick Coal & Coke Co, Harwick, Pa; h, 1127 De Victor Place, Pittsburgh, Pa...**Springdale 204**

Giles, David J. (Associate Member) (April 1917) Metallurgist, Latrobe Electric Steel Co, Latrobe, Pa; h, 621 Walnut St, Latrobe, Pa. ....**Latrobe 650**

Gill, David Donald (Feb. 1924) Manufacturers' Representative, 713 Commonwealth Bldg. Annex; h, 5472 Wilkins Ave, Pittsburgh, Pa .... **Court 0493**

Gillespie, Thomas James, Jr. (Sept. 1915) Secy. & Treas, Lockhart Iron & Steel Co, P. O. Box 1243; h, 619 S. Negley Ave, Pittsburgh, Pa. .... **Federal 1081**

Girdler, Tom M. (Oct. 1928) President, Chairman of Board, Republic Steel Corp, Cleveland, Ohio; h, Academy Ave. Sewickley, Pa.

Giroux, Fred J. (**Junior**) (Dec. 1928) Welding Engr, Roessler & Hassbacher Chemical Co, Niagara Falls; N. Y; h, 521 Cedar Ave, Niagara Falls, N. Y.

Glass, John (Sept. 1912) Chief Engr, Carnegie Natural Gas Co, Waynesburg, Pa; h, Waynesburg, Pa .... **Waynesburg 773**

Glass, Roy Charles (April 1915) Gasoline Engr, Carnegie Natural Gas Co, P. O. Box 716, Waynesburg, Pa; h, Waynesburg, Pa **Waynesburg 773**

Gleason, Donald Thomas (May 1921) Works Mgr, Standard Steel Spring Co, Coraopolis, Pa; h, 1052 Hiland Ave, Coraopolis, Pa .... **Coraopolis 1100**

Gleason, William P. (Jan. 1905) Genl. Supt, Indiana Steel Co, Gary, Ind; h, 670 Jackson St, Gary, Ind.

Godard, Ray S. (April 1926) Glass Factory Engineer, 1702 Grant Bldg; h, Mt. Lebanon Blvd, Mt. Lebanon, Pittsburgh, Pa .. **Atlantic 0712**

★**Godfrey, Edward** (June 1906) Struct. Engr, Robert W. Hunt Co, Professional Bldg; h, 630 Kirtland St, Pittsburgh, Pa .... **Atlantic 3950**

Goodale, Stephen Lincoln (April 1910) Professor of Metallurgy, University of Pittsburgh; h, 1156 Murrayhill Ave, Pittsburgh, Pa .... **Mayflower 3500**

Goodspeed, George M. (March 1912) Metallurgist, National Works, National Tube Co, McKeesport, Pa; h, 1818 Packer St, McKeesport, Pa .... **McKeesport 4144**

Goodwin, Irving Dean (**Associate Member**) (Feb. 1925) Chief Draftsman, Pittsburgh-Des Moines Steel Co, Neville Island P. O; h, 1514 Dormont Ave, S. H, Pittsburgh, Pa .... **Federal 3000**

Gordon, Harold L. (Feb. 1920) Asst. Genl. Mgr, Pittsburgh Limestone Co, Johnson Bldg, New Castle, Pa; h, 2211 N. Highland Ave, New Castle, Pa .... **New Castle 2620**

Gott, Estep Tillard (April 1930) Vice Pres, Dravo Corp, 300 Penn Ave, Pittsburgh, Pa; h, Glen Osborne, Sewickley, Pa ...... **Federal 2600**

★**GRACE, SERGIUS P.** (**Past President 1913**) (Jan. 1903) Asst. Vice Pres, Bell Telephone Laboratories, Inc, 463 West St, New York; N. Y; h, 162 W. 54th St, New York, N. Y.

Graf, Julius E. (Feb. 1926) Asst. Chief Engr, American Sheet & Tin Plate Co, P. O. Box 62, 1222 Frick Bldg; h, 1019 Hamilton Ave, Avalon, Pittsburgh, Pa.................................. **Atlantic 1300**

Graham, Herbert W. (Oct. 1928) Genl. Metallurgist, Jones & Laughlin Steel Corp, Third & Ross St; h, 5437 Ellsworth Ave, Pittsburgh, Pa.. **Court 3240**

Graham, John A. (Sept. 1924) Supt. Buildings & Grounds, Shady Side Academy, Oakland P. O; h, 1002 Delafield Road, Aspinwall, Pittsburgh, Pa.. **Sterling 2400**

Grant, Henry Lee, Jr. (Oct. 1930) Vice Pres, General Explosives Corp, First National Bank Bldg, Latrobe, Pa; h, 1112 Ligonier St, Latrobe, Pa.

Gray, Thomas William (Sept. 1929) Supt. of Mechanical Equipment, Pittsburgh Coal Co. Shops, Library, Pa; h, Loupurex, Pa.

Grayson, Sidney Alwyn (April 1912) President, Jessop Steel Co, Washington, Pa; h, 65 LeMoyne Ave, Washington, Pa... **Washington 2140**

Greenberg, Morris (Nov. 1929) Manager, Pittsburgh Office, Bailey Meter Co, 402 Oliver Bldg; h, Haddon Hall, 4730 Center Ave, Pittsburgh, Pa.. **Atlantic 2530**

Gregg, Lester Osborne (Feb. 1929) Sales Engr, Elliott Co, 718 Frick Bldg; h, 278 Hazel Drive, Mt. Lebanon, Pittsburgh, Pa **Atlantic 5000**

Gressly, Oscar E. (Dec. 1910) Retired, 434 East End Ave, Beaver, Pa. .... **Beaver 1268-R**

Greve, Edgar Eugene (Sept. 1912) Chief Engr, Oil Well Supply Co, Imperial Works, Oil City, Pa; h, 152 Grant Ave, Bellevue, Pittsburgh, Pa.

Grier, Louis N. (Associate) (Feb. 1925) Electrical Engr, Aluminum Co. of America, New Kensington, Pa; h, 365 Riverview Drive, Parnassus, Pa.

Griffiths, Edward McCullough (Dec. 1928) Engineering Dept. Republic Iron & Steel Corp, Youngstown, Ohio; h, 58 Roslyn Drive, Youngstown, Ohio.

Griggs, Thomas Newell (Junior) (Jan. 1928) Attorney at Law, 732 Oliver Bldg; h, 1126 Dartmouth Place, Thornburg, Pittsburgh, Pa...... .... **Atlantic 2370**

Grimes, L. W. David (Junior) (April 1929) Designer; h, 6200 Olivant St, Pittsburgh, Pa.

Grimm, Bruce F. (Oct. 1928) Electrical Engr, The Koppers Coal Co, 1050 Koppers Bldg; h, 3036 Earlsmere Ave, P. O. Box 124, S. H. Sta, Pittsburgh, Pa................................ **Atlantic 6240**

Grobstein, Albert (Feb. 1924) Patent Engineer, 414 Ouray Bldg, Washington, D. C; h, 1300 Taylor St, N. W, Washington, D. C.

Growdon, J. P. (March 1928) Asst. Chief Hydraulic Engr, Aluminum Co. of America, 2400 Oliver Bldg; h, 633 Clyde St, Pittsburgh, Pa. .... **Atlantic 4545**

Guibert, Oscar Eugene (March 1930) President, Guibert Steel Co, 1716 Youghiogheny Ave, Pittsburgh, Pa; h, 1996 Crafton Blvd, Crafton, Pittsburgh, Pa .... **Federal 2960**

Guildbrandsen, Peter (May 1916) Draftsman, Aetna Standard Engrg. Co, 809 Home Savings & Loan Bldg, Youngstown, Ohio; h, P. O. Box 504, Youngstown, Ohio.

Gulick, Henry (Feb. 1903) President, Gulick-Henderson Co, Inc. 19 West 44th St, New York, N. Y; h, 45 Alida St, Yonkers, N. Y.

Gunther, Felix A. (Nov. 1924) Sales Engr, Direct Control Valve Co, 1007 Diamond Bank Bldg; h, R. F. D. No. 9, P. O. Box 137, S. H, Pittsburgh, Pa .... **Atlantic 7435**

Guthrie, James McMurchie (Associate Member) (June 1926) Patent Engr, Christy, Christy & Wharton, 2203 Farmers Bank Bldg; h, 206 Forbes Bldg, Pittsburgh, Pa .... **Atlantic 0386**

Haag, Louis William (May 1923) Chief Engr, Michigan Steel Corp, Ecorse, Detroit, Mich; h, 683 Biddle Ave, Wyandotte, Mich.

Haas, Charles (Associate) (June 1928) President, The Chas. Haas Co, Cuyahoga Falls, Ohio; h, 423 13th St, Cuyahoga Falls, Ohio.

Haddock, Daniel T. (Associate Member) (May 1930) General Sales Dept, American Sheet & Tin Plate Co, 1327 Frick Bldg; h, 15 N. Linwood Ave, Crafton, Pittsburgh, Pa .... **Atlantic 1300**

Hadley, Edward Thomas (Nov. 1921) Draftsman, Ohio Works, Carnegie Steel Co, Youngstown, Ohio; h, 3125 Idlewood St, Youngstown, Ohio.

HAGGART, CECIL NEIL (Chairman Civil Section) (Oct. 1903; May 1912) Consulting Structural Engr, Private Practice, 522-524 335 Fifth Ave; h, 10 Hazel Drive, Mt. Lebanon, Pittsburgh, Pa .. **Atlantic 5349**

Haines, J. Edgar (June 1920) Mech. Engr, Hammer Welding Dept, Christy Park Works, National Tube Co, McKeesport, Pa; h, 989 Greenfield Ave, Pittsburgh, Pa .... **McKeesport 5128**

Haines, William L. R. (Dec. 1928) Asst. Engr, Penna. System, 1126 Penna. Station, Pittsburgh, Pa; h, Riverside Heights, Verona, Pa .... **Grant 6000-Ext. 95**

Haldeman, James F. (Feb. 1917) President, J. F. Haldeman Co, 5941 Baum Blvd; h, 1210 S. Negley Ave, Pittsburgh, Pa .... **Montrose 7198**

Hale, William Thurber (May 1926) Akeley, Warren County, Pa.

Hall, William Ford (Feb. 1910) Dist. Mgr, Raymond Concrete Pile Co, Inc, 1501 Union Bank Bldg; h, 1060 Morewood Ave, Pittsburgh, Pa. . . . . **Court 1436**

Haller, Fred E. (**Associate**) (June 1929) Manager, Mt. Lebanon Garage Co, 600 Washington Road; h, 616 Washington Road, Mt. Lebanon, Pittsburgh, Pa. . . . . **Lehigh 0565**

Haller, Henry E. (May 1921) President, National Valve & Mfg. Co, 3101 Liberty Ave; h, 415 S. Pacific Ave, Pittsburgh, Pa. . . **Atlantic 6730**

Hallett, Henry McLellan (Feb. 1909) Secy. & Dist. Mgr, Pennsylvania Crusher Co, 1445 Oliver Bldg; h, 324 Forest Ave, Ben Avon, Pittsburgh, Pa. . . . . **Atlantic 0839**

Hallgren, Emil (Feb. 1891; Jan. 1912) Private Work, 617 Ridgewood Ave, Pittsburgh, Pa.

Hallock, John Keese (**Associate**) (Feb. 1909) Asst. Sales Mgr, Universal-Atlas Cement Co, 518 Frick Bldg, Pittsburgh, Pa; h, 258 Grant St, Sewickley, Pa. . . . . **Atlantic 2087**

Hamilton, William Bovard (April 1925) Construction Engr, S. S. Works, Jones & Laughlin Steel Corp, 2709 Carson St; h, 1038 Chelton Ave, Brookline, Pittsburgh, Pa. . . . . **Hemlock 0401-Ext. 368**

Hammer, Lewis E. (Dec. 1925) Asst. to Genl. Supt, The Elliott Co, Jeannette, Pa; h, 510 Brandon St, Greensburg, Pa. . . . . . **Jeannette 566**

Hammond, James H. (**Associate**) (April 1913) 1819 Oliver Bldg; h, Woodland Road, Pittsburgh, Pa. . . . . **Atlantic 0736**

Handloser, Bertram F. (**Associate Member**) (Dec. 1924) Asst. Mill Mgr, Dilworth, Porter & Co, Fourth & Bingham Sts; h, 5734 Northumberland St, Pittsburgh, Pa. . . . . **Hemlock 0740**

★**HANDY, JAMES OTIS** (**Past President 1912**) (Nov. 1896) Director of Chemical & Metallurgical Investigations, Pittsburgh Testing Laboratory, Locust & Stevenson Sts, P. O. Box 1115, Pittsburgh, Pa; h, 49 Emerson Ave, New Rochelle, N. Y. . . . . **Grant 3860**

Hansen, William Charles (Feb. 1924) Sales Engr, A. Stucki Co, 419 Oliver Bldg; h, 1115 Davis Ave, Pittsburgh, Pa. . . . . **Atlantic 1250**

Hanson, William Benjamin (**Associate**) (April 1930) Certified Public Accountant, William B. Hanson & Co, Union Trust Bldg; h, 151 Monroe Ave, N. S, Pittsburgh, Pa. . . . . **Atlantic 6494**

Hanst, John Faber (Dec. 1925; April 1930) Mining Engineer, P. O. Box 343, Tuckahoe, N. Y; h, Brook Farm, Crestwood, N. Y.

Harris, Benjamin F. (Sept. 1915; Dec. 1930) President, Oil Well Supply Co, Clark Bldg; h, 1117 S. Negley Ave, Pittsburgh, Pa. . **Atlantic 7980**

Harris, Charles A. (**Associate**) (March 1927) Genl. Storekeeper, Philadelphia Co, 435 Sixth Ave; h, 7502 Church Ave, Ben Avon, Pittsburgh, Pa.......................................**Grant 4300**

Harrop, Harry Stewart (Jan. 1902) Member of Firm, Harrop & Hopkins, 801 Home Trust Bldg; h, 436 South Ave, Wilkinsburg, Pittsburgh, Pa...**Atlantic 3824**

Harshbargar, Elmer Dwight (Oct. 1911) President, The Pitt Construction Co, 701 Starr Bldg, Third & Grant Sts; h, 239 Gladstone Road, Pittsburgh, Pa.................................**Atlantic 5480**

Harter, Isaac (Sept. 1924) Vice Pres, Babcock & Wilcox Co, 85 Liberty St, New York, N. Y; h, 45 E. 82nd St, New York, N. Y.

Harton, Erskine Elliott (Feb. 1914) Production Engr, Treadwell Construction Co, Midland, Pa; h, 408 Fair Ave; Beaver, Pa. **Midland 62**

Hartson, Dorr Parmelee (Sept. 1922) Manager, System Development Dept, Equitable Gas Co, 435 Sixth Ave; h, 1445 Center St, Wilkinsburgh, Pittsburgh, Pa.........................**Grant 7600-Ext. 93**

★**Harvey, Clarke Kennerley** (Dec. 1927) Principal Asst. Engr, Dept. of Public Works, Allegheny County, Bureau of Bridges, Diamond & Ross Sts; h, 933 Fordham St, S. H. Sta, Pittsburgh, Pa.......... ....**Atlantic 4900-Ext. 202**

Haslam, Edwin H. (May 1900) Dist. Mgr, The Elliott Co, Room 1534, 20 N. Wacker Drive, Chicago, Ill; h, Orrington Hotel, Evanston, Ill.

Hatton, Merle W. (June 1913) Res. Engr, Roll & Machine Works, American Sheet & Tin Plate Co, Canton, Ohio; h, 188 33rd St, N. W, Canton, Ohio.

★**HAWLEY, WILLIAM CHAUNCEY** (**Past President 1920**) (Jan. 1903) Chief Engr. & Genl. Supt, Pennsylvania Water Co, 712 South Ave, Wilkinsburg, Pittsburgh, Pa; h, 131 Beech St, Edgewood (Swissvale Sta.), Pa...................................**Penhurst 0107**

Haworth, Mack E. (Jan. 1926) Chief Engr, Hillman Coal & Coke Co, 2307 First National Bank Bldg; h, 16 Stewart Ave, Carrick, Pittsburgh, Pa...**Atlantic 2620**

★**Haydock, Winters** (May 1921) Directing Engr, Dept. of City Transit, City of Pittsburgh, 906 City-County Bldg; h, 2524 Beechwood Blvd, Pittsburgh, Pa.............................**Atlantic 3900**

Hazeltine, Harold L. (April 1926) Engr. of Insulation, The Sterling Varnish Co, Haysville, Allegheny Co, Pa; h, 210 Center Ave, Emsworth, Pa. ....**Sewickley 1550**

Heald, Kenneth Conrad (Jan. 1926) Staff Geologist, The Gulf Refining Companies, 1662 Frick Bldg. Annex, Diamond St; h, 100 Gladstone Road, Pittsburgh, Pa...........................**Atlantic 5300**

Hecht, Max (June 1919) Chief Chemist, Duquesne Light Co. 435 Sixth Ave; h, 6432 Darlington Road, Pittsburgh, Pa........ **Grant 4300**

Heckmon, Charles J. (March 1919) Chief Draftsman, Spang Chalfant & Co, Inc, Etna, Pa; h, 129 Sixth St, Aspinwall, Pittsburgh, Pa. .... **Sterling 0740**

Hefft, Joseph S. (April 1926) Dist. Mgr. Robbins Conveying Belt Co. 942 Union Trust Bldg; h, 1031 King Ave, Pittsburgh, Pa.. **Atlantic 5548**

Heichert, Herman S. (Feb. 1913) Chief Engr, Pittsburgh Plate Glass Co, 2300 Grant Bldg; h, Ruskin Apts, 120 Ruskin Ave, Pittsburgh, Pa.. **Atlantic 5600**

Heinle, Albert W. (Nov. 1921) Consulting Metal-Rolling Engr, 27 Taylor St, Crafton Branch, Pittsburgh, Pa.................. **Walnut 2700**

Heinrichs, Frank Wheddon (Associate Member) (May 1930) Manager, Safety Service Corp, 5021 Liberty Ave, Pittsburgh, Pa; h, R. F. D. No. 1, Verona, Pa.............................. **Montrose 4370**

Helick, Reuben H. (Nov. 1928) Maintenance Engr, Bridges, Dept. of Public Works, Allegheny County, 519 Smithfield St; h, 312 Locust St, Swissvale, Pittsburgh, Pa................ **Atlantic 4900-Ext. 42**

Hellmund, Rudolph E. (Dec. 1926) Chief Electrical Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 7510 Trevanion Ave, Swissvale, Pittsburgh, Pa........................ **Brandywine 1500**

Henderson, Adelbert Andrew (Feb. 1925) Construction Engr, Bureau of Bridges, Dept. Public Works, Allegheny County, 519 Smithfield St; h, 603 Hill Ave, Wilkinsburg, Pittsburgh, Pa..... **Atlantic 4900**

Henderson, David (Associate Member) (April 1914; March 1923) Sales Engr, Dravo-Doyle Co, 300 Penn Ave; h, 334 Orchard Drive, S. H. Pittsburgh, Pa.................................. **Court 5400**

Henderson, Herbert (March 1929) Mgr. of Construction, Gulf Refining Co, P. O. Box 1214; h, Morewood Gardens, Morewood Ave, Pittsburgh, Pa.................................... **Atlantic 5300**

Hendrickson, George L. (March 1929) Asst. Managing Engr, Bureau of Water, City of Pittsburgh, 309 City-County Bldg; h, 28 Bonvue St, Observatory Station, Pittsburgh, Pa...... **Atlantic 3900-Ext. 66**

Hendrix, Walter Willits (Feb. 1913) Vice Pres, Pittsburgh-Des Moines Steel Co, Neville Island; h, 5500 Beverly Place, Pittsburgh, Pa. .... **Federal 3000**

Hengstenberg, Paul M. (Dec. 1917) Head, Experimental Dept, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 508 Jeannette St, Wilkinsburg, Pittsburgh, Pa .... **Brandywine 1500**

Henrici Frederick W. (May 1922) Asst. Engr, Erecting Dept. American Bridge Co, 1526 Frick Bldg; h, 1114 Portland St, Pittsburgh, Pa. .... **Atlantic 4300**

Hensen, Emil (Sept. 1908) Engineer, Jones & Laughlin Steel Corp, Third & Ross St, Pittsburgh, Pa; h, 1107 Woodlawn Drive, Coraopolis, Pa........ **Court 3240**

Heppenstall, Charles William (Jan. 1921) President, Heppenstall Forge & Knife Co, 4620 Hatfield St; h, West Woodland Road, Pittsburgh, Pa........ **Fisk 0800**

Heppenstall, Samuel B. (Oct. 1913) Vice Pres. & Chief Engr, Heppenstall Forge & Knife Co, 4620 Hatfield St; h, 1217 Heberton St, Pittsburgh, Pa........ **Fisk 0800**

Herpel, Harry Conrad (Sept. 1919) Supt. Pipe Mills, National Works, National Tube Co, McKeesport, Pa; h, 1250 Park St, McKeesport, Pa........ **McKeesport 4144**

Herr, Benjamin M. (March 1918) Owner, Herr-Harris Co, Sales Engineers, 910 Fulton Bldg; h, 571 Briar Cliff Road, Pittsburgh, Pa........ **Grant 6475**

Herr, Edwin M. (March 1900) Vice Chairman, Westinghouse Electric & Mfg. Co, 150 Broadway, New York, N. Y; h, 1035 Fifth Ave, New York, N. Y.

Herrmann, John LeRoy (Oct. 1929) Sales Engr, American Gas Accumulator Co, 2882 West Liberty Ave; h, 396 Midway Road, Mt. Lebanon, Pittsburgh, Pa........ **Lehigh 0600**

Herrman, Theodore Joseph (Sept. 1919) Mech. Designer, National Tube Co, National Works, Fourth Ave, McKeesport, Pa; h, 2313 Banker St, McKeesport, Pa........ **McKeesport 5128**

Hersperger, Wade Wilson (Associate) (May 1922) Manager, Chas. Bruning Co, Inc, 646 Grant St, Pittsburgh, Pa; h, 103 Grant Ave, Bellevue, Pittsburgh, Pa........ **Atlantic 8682**

Hertzler, Samuel P. (May 1921) Chief Engr, B. Floersheim & Co, 622 Farmers Bank Bldg; h, 3321 Francisco St, Corliss Sta, Pittsburgh, Pa........ **Atlantic 2224**

Hess, Charles Edward (Oct. 1924) Structural Engr, Private Practice, McCance Block; h, 47 Dallas Ave, Ingram, Pittsburgh, Pa........ **Atlantic 3630**

Hess, Oliver P. (April 1921) Practising Engr, E. W. Hess, Consulting Engineers, 400-401 Deposit National Bank Bldg, Du Bois, Pa; h, 415 S. Church St, Du Bois, Pa........ **Du Bois 1165**

Hester, E. A. (Jan. 1927) Planning Engr, Duquesne Light Co, 435 Sixth Ave; h, 7448 Penfield Court, Pittsburgh, Pa........ **Grant 4300**

Hicks, John Robert (Oct. 1924) Civil & Mining Engr, Eavenson, Alford & Hicks, 1300 Union Trust Bldg; h, 516 Grandview Ave, Mt. Washington, Pittsburgh, Pa .... **Atlantic 3939**

Higgins, Robert Warren (Junior) (June 1927) Service Engr, M. H. Detrick Co, 712 Empire Bldg; h, 4811 Baum Blvd, Pittsburgh, Pa .... **Atlantic 1477**

Higgins, Thomas (Feb. 1916) Genl. Supt, City Mills, Carnegie Steel Co, 35th St, Pittsburgh, Pa; h, Glenshaw, Pa .... **Atlantic 8862**

Hiles, John D. (April 1918) John D. Hiles Co, Oliver Bldg; h, 1031 Mifflin Ave, Edgewood, Pittsburgh, Pa .... **Atlantic 1254**

Hill, B. Houston (Jan. 1913) President, Steam Equipment Mfg. Co, 428 Jenkins Arcade Bldg; h, 5818 Kentucky Ave, Pittsburgh, Pa. .... **Atlantic 6509**

Hill, Charles Montgomery (Associate) (Dec. 1926) Electrical Engr, New York Power & Light Corp, Albany, N. Y; h, University Club, Albany, N. Y.

Hill, Harold Otto (Feb. 1925) Contracting Engr, Riter Conley Works, McClintic-Marshall Co, P. O. Box 939; h, 314 Morrison Drive, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 2562**

Hill, Harry C. (Feb. 1925) h, 201 W. Hutchinson Ave, Edgewood, Pittsburgh, Pa .... **Penhurst 1545**

Hiller, August (Jan. 1924) Industrial Engr, Universal Steel Co, Bridgeville, Pa; h, 3015 Brownsville Road, Mt. Oliver, P. O, Pittsburgh, Pa .... **Bridgeville 34**

Hirsh, William L. (Nov. 1926) Principal Asst. Engr, Bureau of Water, City of Pittsburgh, 311 City-County Bldg; h, 727 Fordham St, Brookline, S. H. Sta, Pittsburgh, Pa .... **Atlantic 3900-Ext. 43**

★**HOBBS, JAMES CLARENCE (Silver Medal 1923)** (Jan. 1916) Supt. of Power, Diamond Alkali Co, Painesville, Ohio; h, 126 Wood St, Painesville, Ohio.

Hockensmith, Wilbur Darwin (Sept. 1915) Pres. & Genl. Mgr, Hockensmith Wheel & Mine Car Co, Penn, Pa; h, Lincoln Highway, Irwin, Pa .... **Jeannette 700-01**

★**Hodgkinson, Francis** (April 1897) Consulting Mechanical Engr, Westinghouse Electric & Mfg. Co, S. Philadelphia Sub-Sta, Lester, Pa; h, Walnut Park Plaza, 63rd & Walnut Sts, Philadelphia, Pa.

Hodgson, Alfred Edward (June 1929) Representative, Baker Raulang Co, 709 Arch St, Philadelphia, Pa; h, 2443 Linden Drive, Merwood Park, Upper Darby, Pa.

★**Hoeveler, John A.** (June 1926) Manager, Engineering Dept, Pittsburgh Reflector Co, 304 Ross St; h, Central Square Apts, B-1, Mt. Lebanon, Pittsburgh, Pa............................**Court 0571**

Hoffmann, James Thomas (Sept. 1926) Patent Engr, U. S. Government, U. S. Patent Office, Div. 13, Washington, D. C; h, Apt. 1016, 2025 I St, N. W, Washington, D. C.

Hoffman, Walter George (March 1929) Chief Engr, Brooke L. Jarrett & Co, 704 Law & Finance Bldg; h, 101 W. Shady Drive, Mt. Lebanon, Pittsburgh, Pa..................................**Atlantic 8439**

Hoffman, William Guy (March 1926) Chief Estimator, American Sheet & Tin Plate Co, Frick Bldg; h, 3 Rosslyn Road, Carnegie, Pa..**Atlantic 1300**

★**Holbrook, Elmer Allen** (Oct. 1927) Dean, Schools of Engineering and Mines, University of Pittsburgh, 104 Thaw Hall; h, 1543 Shady Ave, Pittsburgh, Pa..........................**Mayflower 3500**

Holiday, Harry (Nov. 1923) Works Mgr, Columbia Division, The American Rolling Mill Co, Butler, Pa; h, 434 N. Washington St, Butler, Pa.

Holland, William Jacob (Dec. 1888) President, Carnegie Hero Fund, Director Emeritus, Carnegie Museum and Editor of Publications, Carnegie Museum; h, 5545 Forbes St, Pittsburgh, Pa. **Mayflower 7300**

Holleran, Michael J. (Sept. 1929) Master Mechanic, Booth & Flinn Co, 1942 Forbes St; h, 100 Baldwin Road, Crafton, Pittsburgh, Pa. ....**Grant 0504**

Holmes, Albert Bourne (March 1911) Asst. Supt, Safety, Welfare and Employment, National Works, National Tube Co, McKeesport, Pa; h, 1210 Park St, McKeesport, Pa...........**McKeesport 4144**

Holt, Harris B. (Jan. 1913) Sales Engr, Rosedale Foundry & Machine Co, Washington & Preble Ave, N. S; h, 1710 Montpelier St, Dormont, Pittsburgh, Pa..................................**Cedar 4007**

Holveck, Joseph Emil (Sept. 1915) Vice Pres, The Aldrich Pump Co, (Allentown, Pa.) 1222 Empire Bldg; h, 2008 Crafton Blvd, Crafton, Pittsburgh, Pa..................................**Atlantic 3438**

Homer, William E. (Nov. 1923) Mftrs'. Agent, Crane Packing Co, 99 Vandergrift Bldg; h, 278 Magnolia Ave, Mt. Lebanon, Pittsburgh, Pa..**Court 2571**

Hook, C. Howard (Jan. 1925) Address unknown.

Hooper, Arnold (Associate Member) (April 1930) Dist. Sales Mgr, Blaw-Knox Co, Bucket Dept, 2019 Farmers Bank Bldg; h, 418 Dickson Ave, Ben Avon, Bellevue P. O, Pittsburgh, Pa......**Atlantic 5701**

★**Hopkins, Newton Fisher** (June 1903) Civil and Mining Engr, Harrop & Hopkins, 541 Wood St, Pittsburgh, Pa; h, 515 Hill Ave, Wilkinsburg, Pittsburgh, Pa.............................**Atlantic 3824**

Hopwood, J. M. (May 1921) President, Hagan Corp, Bowman Bldg; h, 2716 Espy Ave, Dormont, Pittsburgh, Pa.............**Court 4724**

Hord, Peyton Robert (June 1920) Engineer; h, 713 Maryland Ave, Pittsburgh, Pa.................................**Mayflower 5354**

Horelick, Samuel (Associate) (April 1925) President, Pennsylvania Transformer Co, 28th St. & A. V. R. R; h, 1110 Cornell St, N. S, Pittsburgh, Pa.......................................**Atlantic 2078**

Horton, W. H. (March 1930) Sales Promotion Mgr, West Penn Power Co, 14 Wood St, Pittsburgh, Pa; h, R. F. D. No. 2, Bridgeville, Pa. ....**Court 4106**

Hosler, Rush Norman (June 1903) Supt, Coal Mine Section, Pennsylvania Compensation Rating & Inspection Bureau, 1004 Payne-Shoemaker Bldg, P. O. Box 46, Harrisburg, Pa; h, 215 Paxtang Ave, Harrisburg, Pa.

Houssman, John (Jan. 1924) Machine Designer, Great Lakes Steel Corp, Detroit, Mich.

Hovey, O. W. (Associate Member) (June 1929) Bridge Designer, Penna. Dept. Highways, Harrisburg, Pa; h, 3203 N. Second St, Harrisburg, Pa.

Howell, Francis Kitchell (Oct. 1919) Sales Engr, Green Fuel Economizer Co, Beacon, N. Y; h, 94 Prospect St, Beacon, N. Y.

Howell, Sidney Albert (Oct. 1929) Pittsburgh Managing Engr, Carboloy Co, Inc, Grant Bldg; h, 600 S. Negley Ave, Pittsburgh, Pa...... ....**Atlantic 6853**

Hower, Harry S. (May 1915; Dec. 1925) Professor and Head, Dept. of Physics, Carnegie Inst. of Technology; h, 5709 Solway St, Pittsburgh, Pa.................................**Mayflower 2600**

Huff, George F. (Dec. 1927) Senior Mech. Engr, Byllesby Engrg. & Management Corp, 435 Sixth Ave; h, 6040 Bryant St, Pittsburgh, Pa..**Grant 5750**

Hufnagel, Frederick B. (Jan. 1907) President, Crucible Steel Co. of America, 2014 Oliver Bldg; h, Woodland Road & Irwin Drive, Sewickley, Pa.......................................**Atlantic 3800**

Hufschmidt, Albert (March 1913) President, J. & J. B. Milholland Co, 714 Fifth Ave; h, 3520 California Ave, Pittsburgh, Pa...**Grant 0223**

Hughes, I. Lamont (Sept. 1926) President, Carnegie Steel Co, Carnegie Bldg; h, William Penn Hotel, Pittsburgh, Pa....... **Atlantic 5100**

Hulbert, Everson C. (Sept. 1916) Civil Engr, Crescent-Portland Cement Co; Wampum, Pa; h, 201 W. Madison Ave, New Castle, Pa .... **Wampum 80**

Hulse, Albert J. (Feb. 1929) Asst. Chief Engr, H. A. Brassert & Co, 310 S. Michigan Ave, Chicago, Ill; h, 7547 Cornell Ave, Chicago, Ill.

Hulse, Shirley Clark (Sept. 1929) Civil Engineer, Bedford, Pa **Bedford 63-W**

Hulst, John (Feb. 1917) Vice Pres, United States Steel Corp, Room 1901, 71 Broadway, New York, N. Y; h, Hotel Pennsylvania, New York, N. Y.

★**HUMPHREY, ARTHUR L.** (**Gold Medal 1917**) (Feb. 1917) President, Westinghouse Air Brake Co, Wilmerding, Pa; h, 361 Maple Ave, Edgewood, Pittsburgh, Pa .... **Brandywine 1490**

Hunt, Roy Arthur (May 1905) President, Aluminum Co. of America, 2400 Oliver Bldg; h, 4875 Ellsworth Ave, Pittsburgh, Pa .. **Atlantic 4545**

Hunter, E. O. (**Associate Member**) (March 1929) Bigelow-Liptak Co, 101 Park Ave, New York, N. Y.

★**HUNTER, JOHN A.** (**Silver Medal 1916**) (**Past President 1927**) (March 1903; April 1910) Asst. Chief Engr, American Sheet & Tin Plate Co, P. O. Box 62, Frick Bldg; h, 151 Dickson Ave, Ben Avon, Pittsburgh, Pa .... **Atlantic 1300**

Hunter, Percy E. (March 1896; April 1910) President, Independent Bridge Co, Neville Island, Pittsburgh, Pa; h, 836 N. Highland Ave, Pittsburgh, Pa .... **Federal 3540**

★**Huntley, Louis Grow** (Oct. 1911) Partner, Huntley & Huntley, 505 Frick Bldg; h, 1333 Squirrel Hill Ave, Pittsburgh, Pa ...... **Atlantic 5615**

Hurtt, William Tisdale (Feb. 1925) Technical Mgr, United Oil Co, Preble & Franklin Ave, N. S, Pittsburgh, Pa; h, 503 Hill Ave, Wilkinsburg, Pittsburgh, Pa .... **Cedar 1270**

Hutchinson, George Cass (March 1916) Dist. Rep, American Abrasive Metals Co, 2101 Farmers Bank Bldg, Pittsburgh, Pa; h, 245 Broad St, Sewickley, Pa .... **Atlantic 0680**

Hutton, Frank E. (**Junior**) (Nov. 1929) Sales Agent, The Babcock & Wilcox Co, 2730 Koppers Bldg; h, Apt. No. 3, 5845 Alderson St, Pittsburgh, Pa .... **Atlantic 0672**

Hyland, C. (March 1930) Dept. Mgr, Goodman Mfg. Co, 4834 Halstead St, Chicago, Ill; h, 6858 Merrill Ave, Chicago, Ill.

Iffarth, William C. (May 1919) Chief Engr, Harbison-Walker Refractories Co, 1802 Farmers Bank Bldg; h, King Edward Apts, Bayard St, Pittsburgh, Pa .... **Atlantic 0942**

Iiams, E. Jay (April 1921) Civil Engineer and Land Surveyor; h, 427 Fifth St, Donora, Pa .... **Donora 10-R**

Ingham, Frank (**Associate Member**) (Oct. 1928) Factory Rep. Baldwin Chain & Mfg. Co, Highland Bldg; h, 1132 Winterton St, Pittsburgh, Pa . . . . **Montrose 6281**

Ingram, Herschel Anthony (Dec. 1922) Sales Agent, The Babcock & Wilcox Co, 2730 Koppers Bldg; h, 341 S. Highland Ave, E. E. Pittsburgh, Pa . . . . **Atlantic 0672**

Irons, Dean M. (April 1925) Asst. Engr, Jones & Laughlin Steel Corp, 311 Ross St, Pittsburgh, Pa; h, 925 Vance Ave, Coraopolis, Pa . . . . **Court 3240**

Irvin, Richard (July 1910) Architect and Engr, Irvin Ramp Co, 99 Vandergrift Bldg; h, 213 Charles St, Knoxville, Pittsburgh, Pa . . **Court 2571**

Irvin, William A. (Dec. 1928) Vice Pres. In Charge Operations, American Sheet & Tin Plate Co, Frick Bldg; h, 901 N. Negley Ave, Pittsburgh, Pa . . . . **Atlantic 1300**

Iversen, Lorenz (June 1914) President, Mesta Machine Co, P. O. Box 1124; h, 5622 Bartlett St, Pittsburgh, Pa . . . . **Homestead 1080**

Jackson, John (Nov. 1910) Vice Pres, The Simonds Mfg. Co, 25th & Liberty Ave; h, 11 Bascom St, N. S, Pittsburgh, Pa . . . . **Grant 0392**

Jackson, William (Jan. 1919) Engineer, American Bridge Co, Frick Bldg, h, 7417 Church Ave, Ben Avon, Pittsburgh, Pa . . . . **Atlantic 4300**

Jackson, William H. (Feb. 1914) President, Pittsburgh-Des Moines Steel Co, Neville Island; h, Schenley Apts, Pittsburgh, Pa . . **Federal 3000**

Jacobs, Nathan B. (April 1921) Vice Pres, Morris Knowles Inc, 507 Westinghouse Bldg; h, 6329 Bartlett St, Pittsburgh, Pa . . . **Atlantic 3882**

★**JAMES HENRY DuVALL** (**Past President 1922**) (Oct. 1902) Consulting Control Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 435 Locust St, Edgewood, Pittsburgh, Pa . . . . **Brandywine 1500-Ext. 9369**

★**James, Joseph Hidy** (Jan. 1911) Professor of Chemistry, College of Engineering, Carnegie Inst. of Technology; h, 5868 Douglass Ave, Pittsburgh, Pa . . . . **Mayflower 2600**

Jamison, William W. (Sept. 1893) Vice Pres, Jamison Coal & Coke Co, Greensburg, Pa; h, 624 N. Main St, Greensburg, Pa. **Greensburg 1980**

★**Jarvis, William Rice** (Feb. 1913) Dist. Mgr, Sullivan Machinery Co, 518 Farmers Bank Bldg; h, 307 S. Graham St, Pittsburgh, Pa . . . . **Atlantic 2792**

Jayme, J. Phillip (July 1911) Crucible Steel Co. of America, W. Lexington Ave. & 42nd St, Chrysler Bldg, New York, N. Y; h, Alger Court, Bronxville, N. Y.

Jefferies, Ernest (Associate Member) (Nov. 1927) Asst. Chief Draftsman, United States Aluminum Co, New Kensington, Pa; h, 519 Woodland Ave, Oakmont, Pa.

Jenkins, Raymond Rhys (May 1924) Sales Engr, General Electric Co, 1316 Oliver Bldg; h, 1118 Kelton Ave, S. H, Pittsburgh, Pa... **Atlantic 6400**

Jenks, Stephen Moore (May 1924) Fuel Engr, American Sheet & Tin Plate Co, Gary Plant, Gary, Ind; h, 764 Buchanan St, Gary, Ind.

Jobke, August F. (Jan. 1927) Electrical and Mechanical Engr; h, 135 Richey Ave, N. S, Pittsburgh, Pa.................. **Fairfax 5796**

Johns, Alexander Watson (May 1922) Borough Mgr, Borough of Ambridge; h, 931 Maplewood Ave, Ambridge, Pa....... **Ambridge 35**

Johns, Thomas R. (June 1929) Genl. Mgr. of Coal Mines, Bethlehem Mines Corp, Johnstown, Pa; h, 146 Montour Ave, (Westmont) Johnstown, Pa.

Johnson, Arthur B. (Feb. 1924) Sales Engr, Standard Steel Car Co, 1120 Frick Bldg; h, 10 Hemlock St, Mt. Lebanon, Pittsburgh, Pa... **Atlantic 1833**

★**Johnson, Charles Morris** (March 1919) Chief Chemist, Park Works, Crucible Steel Co. of America, 30th & Smallman Sts, Pittsburgh, Pa; h, 731 Orchard St, Avalon, Pittsburgh, Pa................ **Atlantic 3800**

Johnson, Fred McCoy (Associate Member) (Oct. 1927) Sales Engr, Chapman-Stein Co, Mt. Vernon, Ohio; h, "Maple Lawn," Mt. Vernon, Ohio.

Johnson, J. A. (June 1928) 1518 E. La Rua St, Pensacola, Fla.

Johnson, John F. (June 1904; May 1914) Engineer, Pittsburgh Plate Glass Co, Grant Bldg, Pittsburgh, Pa; h, 618 Orchard Ave, Bellevue, Pittsburgh, Pa................................ **Atlantic 5600**

Johnston, Edwin Van Deusen (Jan. 1905; Sept. 1913) Engineer; h, 1022 Portland St, Pittsburgh, Pa...................... **Montrose 0674**

★**Johnston, Howard L.** (April 1925) Director, Industrial & Commercial Lighting, Duquesne Light Co, 435 Sixth Ave, Pittsburgh, Pa; h, 242 Avenue A, Wilkinsburg, Pittsburgh, Pa............ **Grant 4300**

Jones, Charles L. (Oct. 1927) Vice Pres, Dry Ice Corp. of America, 52 Vanderbilt Ave, New York, N. Y; h, 54 Storer Ave, Pelham, N. Y.

Jones, David Guy (March 1924) Plant Engr, Pittsburgh Piping & Equipment Co, 43rd & A. V. R. R; h, 3340 Allendale St, Pittsburgh, Pa... **Fisk 1530**

Jones, Jonathan (Dec. 1924) Chief Engr, McClintic-Marshall Co, P. O. Box 1594, Pittsburgh, Pa; h, 816 Eleventh St, Oakmont, Pa... **Atlantic 2562**

Jones, Marshall John H. (Sept. 1923) Genl. Mgr. Penna. Div. Bertha-Consumers Co, 1203 Chamber of Commerce Bldg; h, 5865 Alderson St, Pittsburgh, Pa.............................. **Atlantic 6920**

Jordan, Edward H. (March 1924) Chief Engr, H. J. Heinz Co, 1062 Progress St, N. S; h, 401 Wabana St, N. S, Pittsburgh, Pa...... **Cedar 5700**

★**Joy, Joseph F.** (Sept. 1921) President, Joy Bros, Inc, Church & Pearl Sts, Marion, Ohio; h, Lido Apts, Marion, Ohio.

Judy, Edward W. (Feb. 1930) Vice Pres. and Genl. Mgr, Duquesne Light Co, 435 Sixth Ave; h, 20 Roycroft Ave, Mt. Lebanon, Pittsburgh, Pa.. **Grant 4300**

Kaiser, Benet Joseph (May 1921) Architect, 324 Fourth Ave; h, 521 Bellaire Ave, Pittsburgh, Pa.............................. **Court 0965**

Kaiser, George K. (May 1930) Electrical Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 153 Lloyd St, Edgewood, Pittsburgh, Pa.................................. **Brandywine 1500**

Kalbach, William Robert (Junior) (Nov. 1928) Test Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 500 N. Negley Ave, Pittsburgh, Pa.. **Sterling 2700**

Kaltenbach, Earl G. (Jan. 1930) Special Engr, Dept. of Public Works, Allegheny County, 519 Smithfield St; h, 266 Woodhaven Drive, Beverly Heights, Mt. Lebanon, Pittsburgh, Pa...... **Atlantic 4900**

Karpov, Alexander V. (Dec. 1924) Designing Engr, Aluminum Co. of America, 2426 Oliver Bldg; h, 5643 Northumberland St, Pittsburgh, Pa.................................... **Atlantic 4545**

Kathner, Arthur T. (June 1928) Engineer, Associated with Paul Damiron, 26 Rue Bayard, Paris, France; h, P. O. Box 357, New Cumberland, West Va.

Keagy, Arthur D. (Associate Member) (Dec. 1925) Practicing Engr. & Contractor; h, 34 Altadena Drive, S. H. Sta, Pittsburgh, Pa...... .... **Lehigh 1091**

Keebler, Homer J. (Nov. 1910; Nov. 1920) Engineer; h, 119 Meridan St, Mt. Washington Sta, Pittsburgh, Pa.

Keefer, George M. (Jan. 1907) Sales Mgr, Pittsburgh Branch, Rensselaer Valve Co, 937 Oliver Bldg; h, 446 Kenmont Ave, S. H. Sta, Pittsburgh, Pa.................................... **Atlantic 1636**

Keefer, William W. (Sept. 1903) Kehota Mining Co, First National Bank Bldg; h, 4302 Grant Blvd, Pittsburgh, Pa............ **Atlantic 2311**

Keenan, Albert W. (May 1921) Construction Engr, Cooper Construction Co, Clymer, Indiana Co, Pa; h, 509 S. Lang Ave, Pittsburgh, Pa. .... **Hiland 2865-R**

Keim, Byron L. (March 1923) Mech. Engr, Aluminum Co. of America, Engrg. Dept, 205 Smithfield Bldg; h, 1438 Elm St, Wilkinsburg, Pittsburgh, Pa.................................**Atlantic 4545**

★**Keller, Charles** (March 1895) Retired, 111 S. Lexington Ave, Pittsburgh, Pa...**Hiland 3541**

Keller, John Donald, (Feb. 1928) Mech. Engr, Prof. Trinks, Carnegie Inst. of Technology; h, 3308 Beechwood Blvd, Pittsburgh, Pa. ....**Mayflower 8946**

Keller, William Lloyd (Sept. 1910) Engineer, The Koppers Construction Co, Koppers Bldg; h, 1239 Oakmont St, Crafton Sta, Pittsburgh, Pa..**Atlantic 6240**

Kelley, Henry D. (Feb. 1919) Dist. Mgr, Metal & Thermit Corp, 1514 North Ave, West, N. S, Pittsburgh, Pa...............**Cedar 7987**

Kelly, Augustine B. (April 1927) Treas. & Genl. Mgr, Humphreys Coal & Coke Co, P. O. Box 52, Greensburg, Pa; h, 231 Westmoreland Ave, Greensburg, Pa.............................**Greensburg 7000**

Kelly, Joseph A. (March 1885) President, Reliance Steel Casting Co, 804 Federal Reserve Bldg; h, 5800 Wilkins Ave, Pittsburgh, Pa...... ....**Atlantic 5278**

Kelly, Joseph M., Jr. (May 1921) Hyatt Roller Bearing Co, 806 Fulton Bldg; h, 242 Dan Drive, Pittsburgh, Pa.............**Atlantic 2927**

Kemery, Philo (March 1919) Chairman, Board of Directors, Pittsburgh Engrg, Fdry. & Const. Co, 39th & A. V. R. R; h, 341 Fisk St, Pittsburgh, Pa..**Fisk 3331**

Kendall, Theodore Herman (Associate Member) (Dec. 1926) Genl. Supt. of Distribution, Equitable Gas Co, 435 Sixth Ave; h, 3130 Raleigh St, Dormont, Pittsburgh, Pa..................**Grant 7600-Ext. 49**

Kendall, Verner V. (May 1922) National Tube Co, Dept. of Metallurgy & Research, 1810 Frick Bldg; h, 3112 Pioneer Ave, Dormont, Pittsburgh, Pa.....................................**Atlantic 2500**

Kenderdine, George (Jan. 1916) Asst. Engr, Pennsylvania Railroad Co, 654½ Main St, East Aurora, N. Y; h, 349 Oakwood Ave, East Aurora, N. Y.

Kennedy, Joseph Walker (May 1923) Engineer with Julian Kennedy, 1217 Bessemer Bldg; h, 6401 Darlington Road, Pittsburgh, Pa......... ....**Atlantic 7730**

★**KENNEDY, JULIAN (Past President 1906)** (May 1886) Senior Partner, Julian Kennedy, Engineer, Bessemer Bldg; h, 5400 Forbes St, Pittsburgh, Pa......................................**Atlantic 7730**

Kennedy, Julian, Jr. (June 1922) Julian Kennedy, Engineer, 1217 Bessemer Bldg; h, 230 Thorn St, Sewickley, Pa...............**Atlantic 7730**

Kennedy, Louis P. (**Associate Member**) (May 1929) Sales Dept, General Electric Co, 1314 Oliver Bldg; h, University Club, Pittsburgh, Pa..**Atlantic 6400**

Kennedy, William Ray (**Associate Member**) (June 1930) Sales Engr., Worthington Pump & Machinery Corp., 1945 Koppers Bldg.; h, 1007 Macon Ave., Pittsburgh, Pa.................**Atlantic 4266**

Kenney, Frank M. (Oct. 1925) Section Engr., Duquesne Light Co., 435 Sixth Ave.; h, 129 Heathmore Ave., Brentwood, Pittsburgh, Pa. ....**Grant 3200-Ext. 328**

Keogh, Jere Kenney (**Associate Member**) (May 1921) Sales Rep., Allis-Chalmers Mfg. Co., 815 Park Bldg.; h, 240 Sieaforth Ave., Mt. Lebanon, Pittsburgh, Pa..........................**Atlantic 1729**

Kern, Paul Darlington (Nov. 1929) Checker, Gulf Refining Co, 1301 Law & Finance Bldg; h, 14 Evans Ave, Ingram, Pittsburgh, Pa...... ....**Atlantic 3300**

Kerr, Andrew (Oct. 1902) Engineer, McClintic-Marshall Co, Oliver Bldg; h, 412 Locust St, Edgewood, Pittsburgh, Pa........**Atlantic 2562**

Kerr, Bert A. (April 1921) Engr. and Surveyor, Kerr & Martin, 611 Park Bldg; h, 1227 Wightman St, Pittsburgh, Pa..........**Atlantic 2165**

Khuen, Richard, Jr. (May 1902) Genl. Mgr. Erection, American Bridge Co, Frick Bldg, Pittsburgh, Pa; h, Sewickley, Pa....**Atlantic 4300**

Kiefer, Lewis J. (**Associate Member**) (June 1926) Supt, Farmers Natl. Bank Bldg; 301 Farmers Bank Bldg; h, 10 Perryview Ave, N. S, Pittsburgh, Pa..................................**Atlantic 0453**

Kier, Samuel Martin (Jan. 1909) President, The Kier Fire Brick Co, 1844 Oliver Bldg, Pittsburgh, Pa; h, Salina, Pa......**Atlantic 0957**

Kimmel, Charles Porter (Oct. 1915) Supt, Merchant Mills, Illinois Steel Co, Gary, Ind; h, 720 Jackson St, Gary, Ind.

King, Floyd E. (**Associate Member**) (June 1926) Illuminating Engr, Duquesne Light Co, 435 Sixth Ave, Pittsburgh, Pa; h, P. O. Box 317, Castle Shannon, Pa.....................**Grant 4300-Ext. 215**

Kingsley, Charles Brown (Dec. 1929) Manager, Mississippi Glass Co, Floreffe, Pa; h, 438 Mitchell Ave, Clairton, Pa.

Kinter, Charles Willis (March 1926) Chief Engr, Follansbee Brothers Co, Follansbee, West Va; h, 502 Mahan Ave, Follansbee, West Va.

★**KINTNER, SAMUEL MONTGOMERY** (**Past President 1907**) (Jan. 1901) Head, Research Dept, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa. and President, International Devices Co, 1903 Farmers Bank Bldg; h, 1275 Beechwood Blvd, Pittsburgh, Pa. ....**Brandywine 1500**

Kirk, Ralph L. (Dec. 1926) Asst. to Vice Pres, Duquesne Light Co, 435 Sixth Ave; h, 225 Laurel Ave, Ben Avon, Pittsburgh, Pa . . **Grant 4300**

Kirker, Harry Lepper (Dec. 1909) Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 6734 Thomas Blvd, Pittsburgh, Pa . . . . **Brandywine 1500**

Kirkpatrick, George Myers (Associate Member) (Dec. 1922) Sales Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 1411 Mellon St, Pittsburgh, Pa . . . . **Sterling 2700**

Kiser, A. B. (June 1928) Genl. Supt, Mechanical Equipment, Pittsburgh Coal Co, 1021 Oliver Bldg; h, 52 Hawthorne Ave, Crafton, Pittsburgh, Pa . . . . **Atlantic 2181**

Kline, Robert Stevenson (July 1910) Draftsman, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 465 Dravo St, Beaver, Pa.

Knapp, James Howard (Associate Member) (March 1918) Asst. Supt, Open Hearth Dept, Duquesne Works, Carnegie Steel Co; h, 919 Kennedy Ave, Duquesne, Pa . . . . **Duquesne 5153**

★**Kneass, Strickland, Jr.** (Nov. 1914) Chief Engr, A. M. Byers Co, Ambridge, Pa; h, 55 Thorn St, Sewickley, Pa . . . . **Ambridge 1074**

Knesche, Joseph Albert (April 1928) Mech. Engr, Power Dept, National Tube Co, Frick Bldg, P. O. Box 132; h, 6508 Jackson St, Pittsburgh, Pa . . . . **Atlantic 2500**

Knoble, Edward Frederick (Student Junior) (May 1927) Student, Carnegie Inst. of Technology; h, 1245 Wisconsin Ave, Dormont, Pittsburgh, Pa . . . . **Lehigh 5021-R**

Knopf, Julius R. (Dec. 1920) Secy, Director and Engr, George J. Hagan Co, 1201 Chamber of Commerce Bldg, Pittsburgh, Pa; h, 1715 Montour St, Coraopolis, Pa . . . . **Atlantic 8650**

Knotts, George Walter (April 1899) Dist Mgr, United Engrg. & Fdry. Co, Youngstown, Ohio; h, 275 N. Heights Ave, Youngstown, Ohio.

★**KNOWLES, MORRIS (Past President 1923) (Silver Medal 1920)** (March 1902) Pres. and Chief Engr, Morris Knowles, Inc, 507 Westinghouse Bldg; h, 5814 Stanton Ave, Pittsburgh, Pa . . . . **Atlantic 3882**

Knowlton, Arthur Reid (Associate) (Jan. 1930) Manager, Water Cooler Dept, Ochiltree Electric Co, Empire Bldg; h, 44 Briarcliffe Road, Ben Avon Heights, Pittsburgh, Pa . . . . **Atlantic 1900**

Knox, Francis Henry (June 1891) President, Parr-Shoals Power Co. and Columbia Rwy. Gas & Elec. Co, Mt. Pleasant, S. C; h, Mt. Pleasant, S. C.

Koch, Carlton S. (June 1914) President, Fort Pitt Steel Casting Co, McKeesport, Pa; h, 623 Hampton Ave, Wilkinsburg, Pittsburgh, Pa. . . . . **McKeesport 5186**

Koch, Richard (Oct. 1926) Consulting Elec. Engineer; h, P. O. Box 114, Warwick, Rhode Island.

Koelkebeck, Carl (Junior) (Feb. 1925) Draftsman, Benwood Works, Wheeling Steel Corp, Benwood, West Va; h, Bellview Heights, Bellaire, Ohio.

Kohn, Roy E. (Associate Member) (Oct. 1926) Sales Engr, Crane Co, Chicago, Ill; h, 1616 E. 46th St, East St. Louis, Ill.

Kolb, Frederick L. (Dec. 1929) Sales Engr, Jeffrey Mfg. Co, 600 Second Ave; h, 6379 Burchfield Ave, Pittsburgh, Pa .... **Court 2926**

Kommer, J. Richard (April 1904) Consulting Engineer, P. O. Box 1024, Pittsburgh, Pa.

Kramer, Frank P. (April 1921) Asst. to Dist Engr, American Steel & Wire Co, 830 Frick Bldg; h, 3228 Perrysville Ave, N. S, Pittsburgh, Pa .... **Atlantic 5720**

Kratzer, William N. (April 1903) W. N. Kratzer & Co, 3212-3230 Smallman St, Pittsburgh, Pa; h, Glenfield, Pa .... **Grant 6490**

Kroske, Jacob Frederick (Associate Member) (Oct. 1926) Manager, Pneumatic Tool Sales, Ingersoll-Rand Co, 706 Chamber of Commerce Bldg; h, 578 Peebles St, Wilkinsburg, Pittsburgh, Pa ... **Atlantic 9070**

Kroto, George (Oct. 1924) Dist. Mgr, National Transit Pump & Mach. Co, 1421 Farmers Bank Bldg; h, 230 S. Euclid Ave, Pittsburgh, Pa. .... **Atlantic 1537**

Kruse, Alfred R. (Associate Member) (June 1922) Draftsman, United Engrg. & Fdry. Co, Farmers Bank Bldg; h, 142 Georgetown Ave, West View, Pittsburgh, Pa .... **Atlantic 0863**

Kubitz, Fritz (Feb. 1917) Engineer, 708 Publication Bldg, 209 Ninth St, Pittsburgh, Pa; h, Library, Pa, R. F. D. 1 .... **Atlantic 8059**

Kuhl, Edgar W. (Associate Member) (Nov. 1930) Draftsman, American Sheet & Tin Plate Co, 1220 Frick Bldg; h, 4023 California Ave, N. S, Pittsburgh, Pa .... **Atlantic 1300**

Kuhman, L. F. (March 1923) Manager, Tracyfier Dept, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 138 Overlook Drive, Mt. Lebanon, Pittsburgh, Pa .... **Sterling 2700**

Kuntz, Joseph Franklin (Feb. 1903) Owner, The W. G. Wilkins Co. Engineers, 909 Westinghouse Bldg; h, 4352 Center Ave, Pittsburgh, Pa .... **Atlantic 4141**

Kutchka, Karl Gustav (April 1930) Engineer, Pittsburgh Plate Glass Co, Grant Bldg; h, 609 Whitney Ave, Wilkinsburg, Pittsburgh, Pa. .... **Atlantic 5600**

★**LABOON, JOHN FRANCIS (Director)** (March 1923) Member of Firm, The J. N. Chester Engineers, 813 Clark Bldg; h, 346 Bower Hill Road, Mt. Lebanon, Pittsburgh, Pa................ **Atlantic 1140**

Lacock, J. S. (Associate Member) (Oct. 1927) Sales Engr, Mining Dept, General Electric Co, Oliver Bldg; h, 2231 Shady Ave, Pittsburgh, Pa.. **Atlantic 6400**

★**LADD, GEORGE TALLMAN (Past President 1927)** (Sept. 1902) President and Genl. Mgr, United Engrg. & Fdry. Co, 2307 Farmers Bank Bldg, Pittsburgh, Pa; h, R. D. No. 2, P. O. Box 46, Coraopolis Heights, Coraopolis, Pa........................... **Atlantic 0863**

Ladd, Tallman (March 1930) Sales Engr, Combustion Engineering Corp, 1606 First National Bank Bldg, Pittsburgh, Pa; h, 716 Beaver Road, Sewickley, Pa................................. **Atlantic 1511**

Lagatolla, Paul E. (Junior) (Oct. 1928) Jr. Asst. Engr, Dept. of City Transit, City of Pittsburgh, 906 City-County Bldg; h, 6677 Woodwell St, Pittsburgh, Pa............................ **Atlantic 3900-Ext. 292**

Lahr, Robert W. (March 1926) Draftsman, Phillips Mine & Mill Supply Co, 2227 Jane St, S. S; h, 3716 Evergreen Road, N. S, Pittsburgh, Pa... **Hemlock 0130**

Lail, George G. (Associate Member) (May 1930) Sales Engr, General Electric Co, Oliver Bldg; h, 1302 Woodbourne Ave, Pittsburgh, Pa.. **Atlantic 6400**

Laird, James B. (Associate Member) (Oct. 1929) Mfg. Agent, The Watson Stillman Co, Northern Engineering Works, The Canton Fdry. & Machine Co, Union Trust Bldg; h, 238 Beverly Road, Mt. Lebanon, Pittsburgh, Pa................................ **Atlantic 1535**

Lamb, Warren Vernon (Dec. 1927) Division Engr, Hillman Coal & Coke Co, P. O. Box 610, South Brownsville, Pa; h, P. O. Box 594, Brownsville, Pa.

Lamberger, Louis J. (Feb. 1925) Director, Power and Steam Sales, Duquesne Light Co, 435 Sixth Ave; h, 3325 Latonia Ave, Dormont, Pittsburgh, Pa............................ **Grant 4300-Ext. 211**

★**Lambie, Joseph Sioussa** (June 1923) Operating Mgr, Concrete Products Co. of America, Diamond Bank Bldg; h, 1303 Singer Place, Wilkinsburg, Pittsburgh, Pa........................... **Atlantic 3841**

Lamm, Lee L. (Jan. 1921) R. F. D. No. 2, Edenburg, Pa.

Lanahan, Frank J. (Jan. 1921) President, Fort Pitt Malleable Iron Co, P. O. Box 492; h, 262 Dithridge St, Pittsburgh, Pa.... **Federal 1100**

Land, J. Stanley (Associate Member) (March 1930) National Valve & Mfg. Co, 3101 Liberty Ave; h, 1115 East End Ave, Pittsburgh, Pa. .... **Atlantic 6730**

Landahl, Eugene Everett (Oct. 1927) Construction Engr, The Consolidation Coal Co, Fairmont, West Va; h, 316 Gaston Ave, Fairmont, West Va.

Lane, Harold (June 1922) Draftsman, United Engrg. & Fdry. Co, Farmers Bank Bldg; h, 127 Charles St, Knoxville, Pittsburgh, Pa. **Atlantic 0863**

Langstaff, Harold A. P. (Nov. 1929) Electrical Engr, West Penn Power Co, 14 Wood St; h, 624 Ridgefield Ave, S. H. Sta, Pittsburgh, Pa. .... **Court 4106**

Larned, James Murray (Jan. 1907) Engr. of Way, Pittsburgh Railways Co, 6th Floor, Duquesne Bldg; h, C-1 Alder Court Apts, Alder & Emerson Sts, Pittsburgh, Pa........ **Grant 7450-Ext. 160**

Larson, Walter E. (Sept. 1927) Mech. Engr, Rees Mfg. Co, 7501 Thomas Blvd; h, 914 Milton St, Swissvale, Pittsburgh, Pa... **Churchill 5630**

Lassman, Benjamin (Associate Member) (Feb. 1929) Hydraulic Engr, Oliver Bldg; h, 5857 Bartlett St, Pittsburgh, Pa..... **Atlantic 0932**

Latimer, George B. (Associate Member) (May 1926) Combustion Engineer; h, 286 Mercer Ave, N. E, Warren, Ohio.

Lauer, Willard Wood (Dec. 1915) Const. Engr, Diamond Alkali Co, 248 Bank St, Painesville, Ohio; h, Painesville, Ohio.

Laughlin, Alexander (Feb. 1893) Alex. Laughlin & Co, First National Bank Bldg, Pittsburgh, Pa........ **Atlantic 7600**

Lavine, Saul (Jan. 1925) Sales Engr, General Electric Co, 1314 Oliver Bldg; h, 6400 Bartlett St, Pittsburgh, Pa........ **Atlantic 6400**

Lawlor, Richard C. (Associate Member) (April 1924) Sales Engr, The Anthony Co, 316 Investment Bldg; h, 329 N. Craig St, Pittsburgh, Pa........ **Court 0147**

Lawrence, Charles K. (Jan. 1899) Retired Chief Engr, Central of Georgia Rwy, Savannah, Ga; h, 3303 Abercorn St, Savannah, Ga.

Layng, Frank R. S. (June 1904) Asst. Chief Engr, Bessemer & Lake Erie R. R, Greenville, Pa; h, 387 S. Main St, Greenville, Pa.

Leaf, James Pinney (Feb. 1899) Consulting Engineer, 158 Brighton St, Rochester, Pa; h, 290 West Park, Rochester, Pa... **Rochester 89**

Leathers, Harry M. (Dec. 1923) Dist. Mgr, The Dingle-Clark Co, 311 Ross St; h, 265 Parker Drive, Mt. Lebanon, Pittsburgh, Pa.. **Court 5778**

LeBon, Charles Benoit (Nov. 1928) Chief Draftsman, Pittsburgh Coal Co, Shops, Library, Pa; h, Library, Pa........ **Atlantic 2181**

LeCates, Raymond H. (Junior) (Feb. 1925) Tool Designer, Jones & Laughlin Steel Corp, 27th & Carson Sts, S. S; h, 240 Zara St, Knoxville, Pittsburgh, Pa........ **Hemlock 0401**

Lee, Albert A. (**Associate Member**) (April 1930) Sales Engr, Cutler-Hammer, Inc, 950 Century Bldg; h, 1443 Hillsdale Ave, Dormont, Pittsburgh, Pa .... **Atlantic 4840**

Leebov, Nathan (**Associate Member**) (March 1927) Architectural Engineer, 507 Jones Law Bldg; h, 306-C Saybrook Apts, Craft Ave, Pittsburgh, Pa .... **Court 4221**

Leeper, John B. (**Associate Member**) (Dec. 1923) Manager, Tower Dept, American Bridge Co, 1431 Frick Bldg; Pittsburgh, Pa; h, Glenfield, Pa .... **Atlantic 4300**

Leerberg, Nis (March 1930) Works Engr, Mesta Machine Co, Homestead, Pa; h, 426 Elmer St, Edgewood, Pittsburgh, Pa... **Homestead 1080**

Leet, Clifford S. (July 1911) Land Agent, Bessemer & Lake Erie R. R. Co, 689 Union Trust Bldg; h, 3110 Ashlyn St, Corliss Sta, Pittsburgh, Pa .... **Atlantic 4780**

Legg, Buell Bruce (March 1927) Engineer, Columbia Engineering & Management Corp, 99 N. Front St, Columbus, Ohio, 849 Union Trust Bldg, Pittsburgh, Pa; h, 648 Euclaire Ave, Columbus, Ohio .... **Atlantic 9320**

Lehman, Albert C. (Jan. 1921) President, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, Schenley Apts, Pittsburgh, Pa..... **Sterling 2700**

Lehman, George Mustin (June 1910) Engineer, River Front Improvement, Dept. of Public Works, City-County Bldg; h, 5437 Ellsworth Ave, Georgian Apts, Ellsworth Ave, Pittsburgh, Pa **Atlantic 3900-Ext. 182**

Lehner, George Kriechbaum (April 1903) Partner, J. S. McIlvaine & Co, 406 Trust Co. Bldg; Chambersburg, Pa; h, 590 Montgomery Ave, Chambersburg, Pa.

Leichliter, Otto Gay (April 1927) Genl. Mgr, Reliance Coke & Furnace Co, 514 Frick Bldg; h, 1321 Singer Place, Wilkinsburg, Pittsburgh, Pa. .... **Atlantic 1744**

Leisenring, William Jessup (**Associate Member**) (Nov. 1926) Salesman, American Locomotive Co, Terminal Tower Bldg, Cleveland, Ohio; h, Lake Shore Hotel, 12506 Edgewater Drive, Cleveland, Ohio.

★**Leland, Edward D.** (Nov. 1904) Asst. to Vice Pres, Equitable Gas Co, 435 Sixth Ave; h, 4303 Andover Terrace, Pittsburgh, Pa.. **Grant 7600**

Leonard, James Fulton (Oct. 1925) Engr. of Bridges & Buildings, Pennsylvania R. R, 1106 Pennsylvania Station, Pittsburgh, Pa; h, Glen Osborne, Sewickley, Pa .... **Grant 6000-Ext. 179**

Leonard, Raymond Davis (June 1929) Combustion Engr, Pittsburgh Coal Co, 1027 Oliver Bldg; h, 5506 Harriet St, Pittsburgh, Pa .... **Atlantic 2181**

★**LESHER, CARL EUGENE (Director)** (Dec. 1924) Executive Vice Pres. Pittsburgh Coal Co, 1129 Oliver Bldg, P. O. Box 64, Pittsburgh, Pa; h, 247 Breading Ave, Ben Avon, Pittsburgh, Pa...... **Atlantic 2181**

Lewin, Francis Ashby Wake (Dec. 1926) Dist. Mgr, Coloder Co, Columbus, Ohio; h, 825 East End Ave, Wilkinsburg, Pittsburgh, Pa.. **Penhurst 1837**

Lewis, Essington (Feb. 1927) Managing Director, The Broken Hill Proprietary Co. Ltd, 422 Little Collins St, Melbourne, Australia; h, "Kooringa" Hamilton Ave, Malvern, Melbourne, Victoria, Australia.

★**LEWIS, HARRY J. (Past President 1899)** (May 1890) Consulting Engineer, 336 Fourth Ave; h, 315 Maple Terrace, Pittsburgh, Pa.. **Court 1807**

Lewis, William H. (April 1907) President, Pennsylvania Engineering Works, New Castle, Pa; h, 1060 Devon Road, Pittsburgh, Pa. .... **New Castle 307**

Lindquist, Otto B. (Oct. 1925) Consulting Engr, Allegheny Steel Co, Brackenridge, Pa; h, 1107 Park St, Tarentum, Pa.. **Tarentum 1000**

Lingle, Chester Munson (Feb. 1917) Vice Pres, The Buckeye Coal Co, Nemacolin, Greene County, Pa; h, 108 Ben Lomond St, Uniontown, Pa.

Linn, Guy Fulton (Oct. 1922) Sales Engr, 1503 Oliver Bldg; h, 1427 Elm St, Wilkinsburg, Pittsburgh, Pa.................. **Atlantic 2820**

Little, Samuel Guy (Nov. 1928) Sales Engr, Penn Machine Co, 815 Berger Bldg; h, 425 Franklin Ave, Wilkinsburg, Pittsburgh, Pa... **Court 2561**

Little, William Ross (April 1924) Manager, Pittsburgh District, Fuller-Lehigh Co, 2730 Koppers Bldg; h, 4105 Aliquippa St, Pittsburgh, Pa.. **Atlantic 0672**

Littler, Carl W. (June 1913) Chief Engr, Aliquippa Works, Jones & Laughlin Steel Corp, Aliquippa, Pa.................. **Aliquippa 101-Ext. 6**

Livermore, Arthur C. (Sept. 1920) Vice Pres. and Genl. Mgr, Westinghouse Air Brake Home Bldg. Co, Wilmerding, Pa; h, 223 Chestnut St, Edgewood, Pittsburgh, Pa.................... **Brandywine 1490**

Lloyd, Edward W. (Associate Member) (Oct. 1930) Salesman, Link Belt Co, 436 Seventh Ave; h, 2812 Connecticut Ave, Dormont, Pittsburgh, Pa.. **Atlantic 1692**

Lloyd, Francis J., Jr. (Dec. 1928) Supt, The Dravo Contracting Co, 302 Penn Ave, Pittsburgh, Pa; h, 206 S. Water St, Kittanning, Pa. .... **Court 5400**

Lockhart, John Marshall (March 1917) 1508 Union Bank Bldg; h, 608 N. Highland Ave, Pittsburgh, Pa..................... **Court 1428**

Loeffler, George O. (April 1892; Jan. 1914) Pgh. Rep, Climax Molybdenum Co, 905 Union Trust Bldg; h, King Edward Apts, Bayard & Melwood Sts, Pittsburgh, Pa .... **Atlantic 0622**

Loftus, Peter Francis (Oct. 1925) Consulting Engineer, 441 Oliver Bldg; h, 101 Central Square, Mt. Lebanon, Pittsburgh, Pa .. **Atlantic 1893**

Logan, Harold Milton (Sept. 1919) Chief Engr, Hughes-Foulkrod Co, 421 Seventh Ave; h, 1115 Hillsdale Ave, S. H. Sta, Pittsburgh, Pa .... **Atlantic 7826**

Long, Clarence Edward (April 1921) Civil Engineer, Commonwealth Bldg. Annex, Pittsburgh, Pa; h, Brodhead Hotel, Beaver Falls, Pa. .... **Court 1937**

Longwill, Noble Clayton (**Associate Member**) (March 1930) Draftsman, American Sheet & Tin Plate Co, 1220 Frick Bldg; h, 112 Harlow St, Edgewood, Pittsburgh, Pa .... **Atlantic 1300**

Loomis, De Wayne (March 1894) 1st Vice Pres. & Treas, H. L. Dixon Co, Carnegie, Pa; h, 29 S. Emily St, Crafton, Pittsburgh, Pa. **Walnut 0403**

Loomis, Franklin Wells (May 1927) Vice Pres. and Sales Mgr, Consolidated Lamp & Glass Co, Coraopolis, Pa; h, 1525 Highland Ave, Coraopolis, Pa .... **Coraopolis 6**

Lose, James E. (May 1927) Supt, Carnegie Steel Co, Homestead Steel Works, Munhall, Pa; h, 1021 Savannah Ave, Swissvale, Pittsburgh, Pa .... **Homestead 2603**

Lougee, Lewis Omer (June 1925) Mining Engr, Geo. S. Baton & Co, 2413 First National Bank Bldg; h, 5562 Hobart St, Pittsburgh, Pa. .... **Atlantic 1576**

Loughin, Paul R. (**Associate Member**) (May 1929) Sales Agent, Babcock & Wilcox Co, 2730 Koppers Bldg; h, Apt. No. 8, 42 Academy Ave, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 0672**

Lovett, Sanford C. (**Associate Member**) (Dec. 1926) Sales Engr, General Electric Co, 1318 Oliver Bldg; h, 1466 Alabama Ave, Dormont, Pittsburgh, Pa .... **Atlantic 6400**

Lower, N. M. (Dec. 1924) Lower Stoker Co, McPhail & Hollins St, Baltimore, Md; h, 2200 Garrison Blvd, Baltimore, Md.

Lowrie, William S. (May 1911) Supt. of Machine Shop, The Duraloy Co, New Cumberland, West Va; h, 558 E. Main St, Ravenna, Ohio.

Lubelsky, Benjamin L. (**Associate Member**) (May 1929) Mining Engr, Safety Mining Co, 307 N. Michigan Ave, Chicago, Ill; h, 1211 Savannah Ave, Edgewood, Pittsburgh, Pa .... **Penhurst 7877**

Lundeen, Ernest F. (Oct. 1930) Asst. to Director of Metallurgical Research Div, American Rolling Mill Co, Middletown, Ohio; h, 2203 Linden Ave, Middletown, Ohio.

Luty, Bertrand Elwood Vernon (Feb. 1899) Associate Editor, American Metal Market, 201 Bessemer Bldg; h, 3222 Perrysville Ave, N. S, Pittsburgh, Pa .... **Atlantic 6917**

Lynch, Clay F. (March 1924) Vice Pres. & Genl. Mgr, H. C. Frick Coke Co, 110 Broadway, Scottdale, Pa; h, P. O. Box 62, Greensburg, Pa.

★**Lynch, Tillman D.** (Feb. 1898) Consulting Metallurgical Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 122 Washington Ave, Edgewood, Swissvale P. O, Pittsburgh, Pa . . **Brandywine 1500**

Lynn, Frederick E. (May 1925) Refrigeration Engr, Suburban Electric Development Co, 5624 Penn Ave, Pittsburgh, Pa; h, 312 Moyhend St, Springdale, Pa .... **Montrose 7200**

Lyon, Dugald (Feb. 1922) Mech. Engr, American Sheet & Tin Plate Co, Frick Bldg; h, 632 S. Negley Ave, Pittsburgh, Pa . . . . **Atlantic 1300**

Lyon, John A. (**Junior**) (Dec. 1927) Detailer, Pittsburgh Valve Fdry. & Const. Co, Pittsburgh, Pa; h, 1025 Evergreen Ave, Millvale, Pa. .... **Atlantic 6630**

Lyon, William B. (**Associate**) (April 1930) Manager, Hercules Powder Co, 1126 Fulton Bldg; h, 117 Bower Hill Road, Mt. Lebanon, Pittsburgh, Pa .... **Grant 6171**

Lytle, William Orland (Feb. 1930) Chief Engr, Duplate Corp, Creighton, Pa; h, 264 Freeport Road, New Kensington, Pa.

McAleenan, George Robert (Nov. 1905) President, McAleenan Bros. Co, 25th & A. V. R. R; h, 1733 Beechwood Blvd, Pittsburgh, Pa .... **Atlantic 6540**

McBerty, Don R. (April 1929) Draftsman, Great Lakes Steel Corp, Ecorse, Mich; h, 2754 Pingree Ave, Detroit, Mich.

McBride, James Scott (Nov. 1904) Mechanical Engineer; h, 1601 Elbur Ave, Lakewood, Cleveland, Ohio.

McCabe, William Perry (Feb. 1914) Asst. Engr, Riter-Conley Works, McClintic-Marshall Co, 332 Oliver Bldg; Pittsburgh, Pa; h, 1452 State Ave, Coraopolis, Pa .... **Atlantic 2562**

McClane, William H. (May 1921) Vice Pres, McClane Mining Co, 314 Washington Trust Bldg, Washington, Pa; h, R. D. No. 1, Washington, Pa .... **Washington 375**

McClintic, Howard Hale (Oct. 1892) President, McClintic-Marshall Co, 1219 Oliver Bldg; h, 1130 Beechwood Blvd, Pittsburgh, Pa .... **Atlantic 2562**

McClintock, Frank Stockton (Feb. 1910) Chief Engr, Dravo Doyle Co, 300 Penn Ave; h, 805 Amberson Ave, Pittsburgh, Pa ...... **Court 5400**

★**McCloy, Walter L.** (April 1923) Supt. Lease Dept, Ohio Fuel Gas Co, 99 N. Front St, Columbus, Ohio; h, 2618 Brentwood Road, Bexley, Columbus, Ohio.

★**McConnell, Malcolm Findley** (Nov. 1913) Genl. Supt, Carnegie Steel Co, Mingo Junction, Ohio; h, 405 Belleview Blvd, Steubenville, Ohio.

McConnell, Malcolm R. (**Junior**) (Nov. 1929) Power Sales Engr, West Penn Power Co, 14 Wood St; h, 260 Wood Haven Drive, Mt. Lebanon, Pittsburgh, Pa. . . . . **Court 4106**

McCracken, Charles Kenneth (**Associate Member**) (Nov. 1928) Structural Engr, American Bridge Co, 1422 Frick Bldg, Pittsburgh, Pa; h, 722 Broad St, Sewickley, Pa. . . . . **Atlantic 4300**

McCrystle, Jerome (March 1926) Supt, The Vesta Coal Co, Third & Ross St; h, 1142 Tennessee Ave, Dormont, Pittsburgh, Pa. . . **Court 3240**

★**McCullough, Frank M.** (Jan. 1911) Professor and Head, Dept. of Civil Engineering, Carnegie Inst. of Technology; h, 5454 Fair Oaks St, Pittsburgh, Pa. . . . . **Mayflower 2600**

McCullough, William Thos., Jr. (**Associate Member**) (Dec. 1930) Dist. Sales Mgr, The Babcock & Wilcox Co, 2730 Koppers Bldg; h, University Club, Pittsburgh, Pa. . . . . **Atlantic 0672**

McCune, Joseph C. (Dec. 1927) Asst. Director of Engineering, Westinghouse Air Brake Co, Wilmerding, Pa; h, 1432 Walnut St, Edgewood, Pittsburgh, Pa. . . . . **Brandywine 1490**

McCune, William H. (May 1926) Asst. Metallurgical Engr, American Sheet & Tin Plate Co, 1302 Frick Bldg; h, 5562 Hobart St, Squirrel Hill, Pittsburgh, Pa. . . . . **Atlantic 1300**

McDaniel, Bruce Penn (May 1921) Mgr. of Sales, McClintic-Marshall Co, Oliver Bldg; h, 1442 Murray Ave, Pittsburgh, Pa. . . . **Atlantic 2562**

McDonald, Charles F. (Jan. 1900) Retired; h, 116 S. Fifth St, Duquesne, Pa.

McDonald, Frank A. (March 1895) Genl. Supt, National Mining Co, Morgan, Allegheny Co, Pa; h, 444 Beechwood Ave, Carnegie, Pa. . . . . **Bridgeville 245-J**

McDonald, Louis N. (Jan. 1900) Asst. Genl. Supt, Carnegie Steel Co, Youngstown, Ohio; h, 239 Norwood Ave, Youngstown, Ohio.

McEwen, J. Allen (Dec. 1905) Vice Pres. & Consulting Engr, Pittsburgh Bridge & Iron Works, 703 Fulton Bldg; h, 16 Castle Shannon Road, S. H. Sta, Pittsburgh, Pa. . . . . **Atlantic 9250**

McEwen, J. D. (March 1922) Chief Engr, Lee C. Moore & Co, Inc, 624 Oliver Bldg; h, 212 Catalpa Place, S. H. Sta, Pittsburgh, Pa. . . . . **Atlantic 0808**

McFarlen, Joseph Pettis (Feb. 1926) Sales, General Electric Co, 1316 Oliver Bldg; h, 2730 Broadway, Dormont, Pittsburgh, Pa.. **Atlantic 6400**

McGannon, Frank Edward (June 1926) Supt. Construction, H. E. Culbertson Co, 1301 Clark Bldg; h, 99 Dewey Ave, Crafton, Pittsburgh, Pa.. **Atlantic 0812**

McGarvey, Albert Gayton (May 1922) Chief Engr, The Pittsburgher Hotel, Diamond & Cherry Sts, Pittsburgh, Pa; h, R. F. D. No. 2, Bridgeville, Pa.................................. **Atlantic 6970**

McGee, Frank Raymond (April 1911) Mech. Engr, Carnegie Steel Co, Mingo Junction, Ohio; h, 1121 Oregon Ave, Steubenville, Ohio.

McGinnis, Thomas Polk (Associate Member) (Nov. 1929) Dist. Sales Mgr, The Pyle-National Co, 420 Oliver Bldg; h, 147 Ridge Ave, Ben Avon, Pittsburgh, Pa.............................. **Atlantic 0974**

McGonagle, Arthur (Sept. 1923) Consulting Engineer, 1013 Fulton Bldg; h, 6815 Prospect Ave, Ben Avon, Pittsburgh, Pa...... **Atlantic 9688**

McGovern, Thomas J. (April 1921) Engineer for Carrick, Brentwood, Mt. Oliver, St. Clair and Hays Boroughs, 300 Brownsville Road; h, 2048 Brownsville Road, Mt. Oliver, Pittsburgh, Pa.... **Lafayette 0109**

McGrath, Martin H. (Associate) (Dec. 1926) Electrical Engr, General Cable Corp, Graybar Bldg, Lexington Ave, New York, N. Y; h, 126 Washington St, Perth Amboy, New York.

McGrew, Anson Burlingame (Dec. 1927) U. S. Assoc. Engr, U. S. Engineer Dept, 1602 Keenan Bldg, Pittsburgh, Pa; h, 259 Taylor Ave, Beaver, Pa.. **Atlantic 5958**

McIlvried, Howard George (March 1926) Asst. Chief Engr, American Sheet & Tin Plate Co, Gary Tin Mill, Gary, Ind.

McInerney, William I. (Dec. 1925) Supt, Heat Treating & Cold Drawing Depts, Pittsburgh Crucible Steel Co, Midland, Pa; h, 1133 Ohio Ave, Midland, Pa.................................. **Midland 51**

McIntire, Thomas Brown (May 1913) Secy. and Treas, Middleman-McIntire Corp, 539 Fourth Ave; h, 350 S. Atlantic Ave, Pittsburgh, Pa. .... **Court 2667**

McIntosh, F. F. (Feb. 1911; Oct. 1925) Metallurgist, Crucible Steel Co. of America, 2014 Oliver Bldg, Pittsburgh, Pa; h, Glen Osborne, Sewickley, Pa.. **Atlantic 3800**

McIntyre, Lewis W. (Dec. 1927) Chief Engr, Bureau of Traffic Planning, City of Pittsburgh, 908 City-County Bldg; h, 6630 Woodwell St, Pittsburgh, Pa.......................... **Atlantic 3900-Ext. 283**

McKean, Robert A. (June 1910) Genl. Mgr, Riter Conley Works, McClintic-Marshall Co, P. O. Box 1594; h, Schenley Apts, Pittsburgh, Pa. .... **Atlantic 2562**

McKee, Frederick Chadwick (Associate) (Dec. 1926) Vice Pres, West Penn Cement Co, 2215 Oliver Bldg; h, Webster Hall, Pittsburgh, Pa .... **Atlantic 2476**

McKee, Waldo McCutcheon (Associate Member) (Oct. 1927) Sales Mgr, The Tri-Lok Co, 5555 Butler St; h, 42 S. Freemont St, Bellevue, Pittsburgh, Pa .... **Fisk 2750**

McKee, William Meek (Dec. 1916) President, W. M. McKee, Inc, Mftrs'. Agent, 436 Oliver Bldg; h, University Club, Pittsburgh, Pa .... **Atlantic 4658**

McKenna, Roy Carnegie (Dec. 1928) President, Vanadium-Alloys Steel Co, Colonial Steel Co, Anchor Drawn Steel Co, McKenna Brass & Mfg. Co, 324 Fourth Ave, Keystone Bldg; h, P. O. Box 236, Latrobe, Pa .... **Court 0582**

McKenzie, Charles Louis (Sept. 1903) President, Duquesne Slag Products Co, 808 Diamond Bank Bldg, Pittsburgh, Pa .... **Atlantic 3841**

McKinley, Joseph (Dec. 1915) Vice-Pres. In Charge of Sales, Philadelphia Co, 435 Sixth Ave; h, 940 Farragut St, Pittsburgh, Pa .... **Grant 4300**

McKinney, Robert Marshall (April 1921) Civil & Mining Engineer, Dravosburg, Pa .... **McKeesport 7732**

McKinnon, Norman Charles (Junior) (Oct. 1930) Representative, Lewis Corp, Minneapolis, Minn; h, 712 School St, McKees Rocks, Pa. .... **Atlantic 8741**

McKown, Howard Purcell (Feb. 1927) President, J. Toner Barr Co, 1600 Princess St; h, 219 Princeton Ave, West View, Pittsburgh, Pa. .... **Lehigh 4500**

McLean, Harold Alfred (Associate Member) (April 1927) President, W. B. McLean Mfg. Co, 65 Imperial Power Bldg; h, 6755 McPherson Blvd, Pittsburgh, Pa .... **Court 2961**

★**McLoughlin, Thomas J.** (March 1919) Fuel Engr, Carnegie Steel Co, Duquesne, Pa; h, 706 Crawford St, Duquesne, Pa. **Duquesne 5153**

McMichaels, W. A. (Nov. 1924) Engineer, 381 Second St, Pitcairn, Pa.

McMillen, Albert Knox (May 1912) Chief Engr, Alex. Laughlin & Co, 1801 First National Bank Bldg; h, 2764 S. Bergman St, Pittsburgh, Pa .... **Atlantic 7600**

McMillen, Russell H. (June 1918) Metallurgist, La Belle Works, Crucible Steel Co. of America, Ridge Ave. & Reedsdale St; h, 1115 King Ave. Pittsburgh, Pa .... **Atlantic 3800**

McMillin, O. B. (April 1922) Metallurgist, Pittsburgh Rolls Corp, 41st & Willow Sts; h, 7534 Bennett St, Pittsburgh, Pa........ **Fisk 2490**

McMullen, Philip S. (April 1921) Civil Engr. and Land Surveyor, Official Borough Engr, Glassport, Pa; h, Pacific & Summit Ave, Glassport, Pa.. **Glassport 1-M**

★**McNaugher, David White** (Dec. 1896) Vice Pres. and Treas, Robert W. Hunt Co, Professional Bldg, 429 Penn Ave; h, 2301 Osgood St, Pittsburgh, Pa................................ **Atlantic 3950**

McNeil, Donald (Jan. 1909) President, The Donald McNeil Co, Winebiddle Ave. & P. R. R; h, 455 S. Atlantic Ave, Pittsburgh, Pa.......... .... **Montrose 5715**

McNiff, Gilbert P. (June 1917) Asst. Vice Pres, National Tube Co, 1711 Frick Bldg, P. O. Box 132; h, 5826 Marlborough St, Pittsburgh, Pa.. **Atlantic 2500**

McQuiston, William Bryce (Nov. 1925) Salesman, Kier Fire Brick Co, 1844 Oliver Bldg; h, 6315 Bartlett St, Pittsburgh, Pa.. **Atlantic 0957**

McRoberts, William H. (June 1924) Chief of Survey Corps, State Dept. of Highways, 55 Water St, Pittsburgh, Pa; h, 538 Dawson Ave, Bellevue, Pittsburgh, Pa................................ **Court 4150**

McWade, Frank J. (Jan. 1926) Supervising Engr, Real Estate Dept, Firestone Tire & Rubber Co, Akron, Ohio; h, 1257 Wisconsin Ave, Dormont, Pittsburgh, Pa........................ **Lehigh 1588-R**

MacDonald, Rowland (Oct. 1929) Mech. Engr, Westinghouse Electric & Mfg. Co, Page Blvd, Springfield, Mass; h, 9 Pelham St, Worcester, Mass.

MacGaugh, Myles C. (Junior) (June 1929) Draftsman, City of Pittsburgh, Dept. of City Transit, 906 City-County Bldg, Pittsburgh, Pa; h, 530 Pennsylvania Ave, Oakmont, Pa................ **Atlantic 3900**

MacGregor, John R. (Associate Member) (Dec. 1928) Chief Engr, Bell Telephone Co. of Penna, 416 Seventh Ave; h, 453 Dawson Ave, Bellevue, Pittsburgh, Pa.................. **Official 0050-Ext. 720**

Mackenzie, James J. P. (Junior) (Feb. 1929) Sales Engr—Address unknown.

MacLachlan, Robert (Feb. 1929) Plant Supt, Champion No. 3 Preparation Plant, Research Div, Pittsburgh Coal Co, Library, Pa; h, R. D. No. 1, Library, Pa........................... **Library 52**

MacVean, Gordon (Associate Member) (April 1930) Asst. Sales Mgr, Edison Lamp Dept., Mine Safety Appliances Co, 201 N. Braddock Ave; h, Pittsburgh Athletic Association, Pittsburgh, Pa.......... .... **Churchill 5900**

Magill, Franklin R. (March 1924) Sales Engr, The Dingle-Clark Co, Room 307, 311 Ross St; h, 509 Lyndhurst Ave, S. H. Sta, Pittsburgh, Pa. . . . . **Court 5778**

Magnani, Charles (Sept. 1924) Asst. to Engineer, Power Investigating Committee, U. S. Steel Corp, 1228 Frick Bldg, P. O. Box 132; h, 1208 Kelton Ave, Dormont, Pittsburgh, Pa. . . . . **Atlantic 1300**

Malady, John A. (April 1925) Mech. and Elec. Engr; h, 46 Stewart Ave, Carrick, Pittsburgh, Pa. . . . . **Carrick 2761-R**

Malevich, Vladimir (Dec. 1925) Structural Engr, Jones & Laughlin Steel Corp, 3450 Second Ave; h, 344 Becks Run Road, Pittsburgh, Pa. . . . . **Atlantic 9670**

Mali, Franklin F. (May 1922) Works Engr, National Electric Products Corp, National Metal Molding Division, Ambridge, Pa; h, 801 Sixth St, New Brighton, Pa. . . . . **Ambridge 15**

Malmstrom, Uno W. (May 1911) Chief Engr, J. A. Roebling's Sons Co, 612 S. Broad St, Trenton, N. J; h, 853 Highland Ave, Morrisville, Pa.

Malseed, William H. (**Associate Member**) (Dec. 1925) Supt, Cuthbert Bros. Co, Bessemer Bldg, Pittsburgh, Pa; h, 409 Windsor St, McKeesport, Pa. . . . . **Grant 5736**

★**MANDEVILLE, J. BRADLEY** (**Silver Medal 1921**) (June 1916) Gas Engr, Minnesota Northern Power Co, Minneapolis, Minn; h, 831 Second Ave, South, Minneapolis, Minn.

Mann, Harvey B. (April 1924) Vice Pres, Dravo-Doyle Co, Dravo Bldg, 302 Penn Ave; h, 7302 Brighton Road, Ben Avon, Pittsburgh, Pa. . . . . **Court 5400**

Mansfield, Myron G. (**Associate Member**) (April 1926) Division Engr, & Secy, Morris Knowles, Inc, 507 Westinghouse Bldg; h, 7046 Penn Ave, Pittsburgh, Pa. . . . . **Atlantic 3882**

Mantle, Gregory Douglas (March 1923) Mantle Recuperator Div, The Surface Combustion Co, Inc, Oliver Bldg; h, 5738 Kentucky Ave, Pittsburgh, Pa. . . . . **Atlantic 9191**

Marshall, Charles D. (May 1896) President, McClintic-Marshall Co, 1217 Oliver Bldg; h, 6300 Fifth Ave, Pittsburgh, Pa. . . . . **Atlantic 2562**

Martin, Charles A. (Oct. 1921) Engr. and Surveyor, Kerr & Martin, 611 Park Bldg, Pittsburgh, Pa; h, 1450 Ridge Ave, Coraopolis, Pa. . . . . **Atlantic 2165**

Martin, George F, Jr. (**Student Junior**) (Oct. 1927) Asst. Metallurgist, Carnegie Steel Co, Homestead, Munhall, Pa; h, 802 Ross Ave, Wilkinsburg, Pittsburgh, Pa. . . . . **Homestead 2603**

★**MARTIN, JAMES STEWART (Silver Medals 1918-1922)** (March 1913) Chief Structural Engr, Walter Bates Steel Corp, Gary, Ind; h, 470 Hayes St, Gary, Ind.

Martin, John M. (Jan. 1903) Manager Shiffler Plant, American Bridge Co, 115 51st St; h, 5396 Wilkins Ave, Pittsburgh, Pa..... **Atlantic 4300**

Martin, Park H. (April 1921) President, McBride Surveying & Engrg. Co, Ltd, 331 Fourth Ave, Pittsburgh, Pa; h, 44 N. Howard Ave, Bellevue, Pittsburgh, Pa.............................. **Court 1787**

Mason, E. J. (Jan. 1903) Asst. Engr, Heyl & Patterson, Inc, 50 Water St, Pittsburgh, Pa; h, 56 Taylor St, Crafton, Pittsburgh, Pa.. **Court 0753**

Mason, J. Robert (Associate Member) (Jan. 1914) Dist. Sales Engr, The Wickes Boiler Co, 1218 Empire Bldg; h, 3240 Beechwood Blvd, Pittsburgh, Pa.................................. **Grant 8294**

Masters, William C. (April 1920) Sales Engr, Pittsburgh Screw & Bolt Co, Pittsburgh, Pa; h, 1046 Vance Ave, Coraopolis, Pa.... **Linden 5300**

Matheson, Charles P. (April 1921) Vice Pres. and Treas, Pittsburgh Building Specialties Co, 1105 Jones Law Bldg; h, 660 Maryland Ave, Pittsburgh, Pa.................................. **Court 4296**

Mathieu, Henry Philip (Associate Member) (Nov. 1928) Sales Engr, Dravo-Doyle Co, 300 Penn Ave, Pittsburgh, Pa; h, 902 Forrest Ave, Ross Township, Pittsburgh, Pa................ **Court 5400**

Mauser, Louis K. (Associate Member) (Nov. 1926) Commercial Development, 908 Mahoning Bank Bldg, Youngstown, Ohio; h, 174 W. Glenaven Ave, Youngstown, Ohio.

Mayer, Raoul G. (Dec. 1927) Designer, National Tube Co, McKeesport, Pa; h, 1436 Elm St, Wilkinsburg, Pittsburgh, Pa.. **McKeesport 4144**

Mechesney, Charles Alexander (Jan. 1924) Engineer, Equitable Gas Co, and Pittsburgh & West Virginia Gas Co, 435 Sixth Ave; h, 404 Center St, Wilkinsburg, Pittsburgh, Pa....... **Grant 7600-Ext. 40**

Medley, Harold C. (Associate Member) (June 1923) Draftsman, Heyl & Patterson, Inc, 50 Water St; h, 417 Sinton Ave, Carrick, Pittsburgh, Pa.. **Court 0753**

Meermans, Leonard H. (Junior) (Nov. 1929) Cadet Engr, Equitable Gas Co, 435 Sixth Ave; h, 4 Buffalo St, Pittsburgh, Pa...... **Grant 7600**

Meharg, Laurence (June 1924) h, Beech Glen, Wheeling, West Va.

Mekeel, David Lane (Feb. 1901) Chief Engr, Jones & Laughlin Steel Corp, 315 J & L Bldg, Pittsburgh, Pa; h, Coraopolis, Pa...... **Court 3240**

Melcher, John P. (Sept. 1924) Pittsburgh Valve, Fdry. & Const. Co, P. O. Box 1016; h, 357 West Penn Place, Pittsburgh, Pa... **Atlantic 6630**

Mellsop, Clifton E. (May 1910) Engineer, Riter Conley Works, McClintic-Marshall Co, 1207 Oliver Bldg; h, 7462 Penfield Court, Pittsburgh, Pa.......................................**Atlantic 2562**

Menaglia, V. A. (March 1929) Sales Engr, S. K. F. Industries, 923 Grant Bldg; h, 7125 McPherson Blvd, Pittsburgh, Pa......**Atlantic 7440**

Merrill, Ferrand Seymour (Nov. 1926) Asst. to Div. Engr, American Bridge Co, 1422 Frick Bldg, Pittsburgh, Pa; h, 509 Glen Mitchell Road, Sewickley, Pa..............................**Atlantic 4300**

Messler, Eugene L. (Jan. 1901) President, Eureka Fire Brick Works, 1507 First National Bank Bldg; h, 5423 Forbes St, Pittsburgh, Pa. ....**Atlantic 0640**

Metzger, William F. (Associate Member) (Dec. 1926) Vice Pres, H. O. Swoboda, Inc, 3400 Forbes St; h, 1502 Hetzel St, N. S, Pittsburgh, Pa......................................**Mayflower 8356**

Meyer, Paul Abner (Sept. 1905) h, 413 W. Third St, Greensburg, Pa.

Meyran, Louis A. (Jan. 1884) Vice Pres, Manufacturers Light & Heat Co, Union Bank Bldg; h, 1125 Shady Ave, Pittsburgh, Pa..**Court 1311**

Middleton, Raymond T. (May 1925) Contracting Engr, Roberts & Schaefer Co, 417 Oliver Bldg; h, 5329 Beeler St, Pittsburgh, Pa..**Atlantic 4881**

Mikaloff, John P., Jr. (Nov. 1926) Asst. Fuel Engr, Carnegie Steel Co, Duquesne, Pa; h, 220 W. Oliver Ave, Duquesne, Pa. **Duquesne 5153**

Millar, Roger Alexander (March 1930) Sales Mgr, Wm. H. Barr, Inc, 27 Carolina St, Buffalo, N. Y; h, Stuyvesant Hotel, Buffalo, N. Y.

Millard, Emmor Hamilton (Jan. 1924) President, Steel Frame House Co, Oliver Bldg; h, 213 Chestnut Road, Edgeworth, Sewickley, Pa. ....**Atlantic 2562**

Miller, Cyrus E. (April 1921) Registered Engineer, 5147 Jenkins Arcade Bldg; h, 147 Grant Ave, Bellevue, Pittsburgh, Pa....**Atlantic 9065**

Miller, Harry Rhodes (Jan. 1923) Chief Engr, Pittsburgh Coal Co, 1012 Oliver Bldg, Pittsburgh, Pa; h, Elizabeth, Pa.........**Atlantic 2181**

Miller, Henry Barron (May 1923) Retired Mining Engr; h, 35 Hilaire Road, St. Davids, Delaware Co, Pa.

Miller, James M. (May 1923) Genl. Mgr, Penn Electrical Co, Irwin, Pa; h, 14 First St, North Irwin, Irwin, Pa................**Irwin 83**

Miller, John F. (Feb. 1921) Vice Chairman of the Board, Westinghouse Air Brake Co, Wilmerding, Pa; h, 222 Hawthorne St, Edgewood, Pittsburgh, Pa..............................**Brandywine 1490**

Miller, Joseph Torrence (Jan. 1903; May 1926) Secy, Treas. and Pur. Agt, Pennsylvania Water Co, 712 South Ave, Wilkinsburg, Pa; h, 424 Maple Ave, Edgewood, Pittsburgh, Pa......**Penhurst 0910**

Miller, Lyman H. (March 1925) Asst. Supt, American Steel & Wire Co, Braddock, Pa; h, 549 S. Braddock Ave, Pittsburgh, Pa........ .... **Brandywine 3350**

Miller, William Booth (Dec. 1899) Pres. and Treas, Pihl & Miller, Contracting Engineers, Wabash Bldg, Pittsburgh, Pa; h, 520 Pine Road, Sewickley, Pa.................................... **Court 1670**

Milliken, James (Dec. 1919) President, Pittsburgh Testing Laboratory, Stevenson & Locust Sts, P. O. Box 1115; h, 4914 Center Ave, Pittsburgh, Pa.. **Grant 3860**

★**Mills, Charles Peale** (Oct. 1927) Director of Chrome Alloy Dept, General Alloys Co, Champaign, Ill; h, 1015 West Hill St, Champaign, Ill.

Mills, Guy Gregory (Oct. 1930) Dist. Mgr, The Kinnear Mfg. Co, 1723 Oliver Bldg; h, 6906 Thomas Blvd, Pittsburgh, Pa... **Atlantic 2414**

Milton, A. Loring (June 1922; Oct. 1925) Mech. Engr, Wheeling Steel Corp, Benwood, West Va; h, 16 Echo Terrace Ave, Wheeling, West Va.

Miner, Philip H. (**Associate Member**) (Oct. 1924) Chief Engr, Tracyfier Dept, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 540 Orchard Ave, Bellevue, Pittsburgh, Pa...................... **Sterling 2700**

Minnotte, Joseph F. (April 1929) Secy. and Treas, Minnotte Brothers Co, Inc, 1201-1202 House Bldg; h, 371 Orchard Drive, Mt. Lebanon, Pittsburgh, Pa.............................. **Court 0637-0638**

Mitchell, H. L. (April 1930) President, West Penn Power Co, 14 Wood St; h, 6334 Forbes St, Pittsburgh, Pa................. **Court 4106**

Mitchell, Robert A. (Feb. 1924) Engineer, Link Belt Co, 2125 Koppers Bldg; h, Pittsburgh Athletic Association, Pittsburgh, Pa........ .... **Atlantic 1692**

Mitchell, Thomas J. (June 1924) Vice Pres, Crescent Brick Co, 2515 Grant Bldg; h, 1617 Falk Ave, N. S, Pittsburgh, Pa........ **Atlantic 7820**

Moeller, Nils D. (Oct. 1924) Mech. Engr, The Koppers Construction Co, Koppers Bldg; h, 1510 Hillsdale Ave, Dormont, Pittsburgh, Pa. .... **Atlantic 6240-Ext. 479**

Monk, P. S. (Feb. 1924) Designing Engr, Norman S. Sprague, Consulting Engineer, 1011 Bessemer Bldg; h, 1219 Morningside Ave, Pittsburgh, Pa... **Atlantic 9518**

Monro, William L. (Jan. 1921) Pres. and Genl. Mgr, American Window Glass Co, Farmers Bank Bldg; h, 5840 Wilkins Ave, Pittsburgh, Pa... **Atlantic 0449**

Monroe, Robert A. (June 1930) Civil and Hydraulic Engr, Aluminum Co. of America, 2400 Oliver Bldg; h, 415 Parker Ave, Mt. Lebanon, Pittsburgh, Pa................................. **Atlantic 4545**

Moore, Emmett Hayden (**Associate Member**) (Feb. 1925) Junior Designer, Allegheny County, 519 Smithfield St, Room 101; h, 101 Emerson Ave, Aspinwall, Pittsburgh, Pa .... **Atlantic 4900-Ext. 44**

Moore, H. Lee (Oct. 1918) Manager Pittsburgh Office, Buffalo Forge Co, 927 Union Trust Bldg; h, 7065 Flaccus Road, Ben Avon, Pittsburgh, Pa .... **Atlantic 3581**

Moore, Lee C. (Jan. 1906; Sept. 1924) Mech. Engr, Lee C. Moore & Co, Inc, 612 Philtower Life Bldg, Tulsa, Okla; h, Tulsa, Okla.

Moore, Ralph Waldo Emerson (Oct. 1927) Engrg. Mgr, Assn. Activities, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, Cathedral Mansions, Ellsworth Ave, Pittsburgh, Pa .... **Brandywine 1500**

★**Moore, William E.** (June 1918) President, W. E. Moore & Co, P. O. Box 1125; h, 368 S. Evaline St, Pittsburgh, Pa .... **Grant 6221**

Moreland, William C. (Jan. 1904) Vice Pres, Jones & Laughlin Steel Corp, J. & L. Bldg, Pittsburgh, Pa; h, Coraopolis Heights, Coraopolis, Pa .... **Court 3240**

Morgan, Edward F. (Feb. 1924) Partner, E. F. Morgan Co, 1517 Clark Bldg, Pittsburgh, Pa; h, R. D. No. 1, Allison Park, Pa .. **Atlantic 1565**

Morganstern, Ralph M. (June 1902) Owner, Morganstern Electric Co, 334 Second Ave; h, 5421 Maynard St, Pittsburgh, Pa .... **Court 1106**

Morganstern, W. C. (Oct. 1924) Steam Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 308 Dunlap Ave, Pittsburgh, Pa. **Sterling 2700**

Morison, George Smith (June 1924) Pres. and Engr, Morison Incorporated, 246 Third Ave; h, Loutellus Apts, 245 Melwood Ave, Pittsburgh, Pa .... **Court 2675**

Morris, Alfred A. (Oct. 1924) Lubrication Engr, Gulf Refining Co, Gross St. & P. R. R, Pittsburgh, Pa; 313 Penwood Ave, Wilkinsburg, Pittsburgh, Pa .... **Schenley 1000**

Morrison, B. Frank (Jan. 1930) Sales Engr, Worthington Pump & Machinery Corp, 1945 Koppers Bldg; h, 441 Clokey Ave, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 4266**

Morrison, George W. (Feb. 1924) Dist. Mgr, Vanadium Alloys Steel Co, 240 Plainfield St, Springfield, Mass; h, 70 Leyfred Terrace, Springfield, Mass.

Morrison, Thomas (April 1893) Retired, 1315 Highland Bldg, Pittsburgh, Pa .... **Montrose 8104**

Morrow, J. B. (May 1930) Preparation Engr, Pittsburgh Coal Co, Oliver Bldg; h, 732 Roselawn Ave, Pittsburgh, Pa .... **Atlantic 2181**

★**MORSE, EDWIN KIRTLAND** (**Past President 1910**) (Jan. 1896) Consulting Engineer, Private Practice, 345 Fourth Ave; h, 255 N. Craig St, Pittsburgh, Pa .... **Court 0170**

Morse, George H. (March 1927) Manager, Northern Coal Mines, Republic Steel Corp, 1743 Oliver Bldg; h, 1338 Sheridan Ave, Pittsburgh, Pa..**Atlantic 2253**

Morton, William Alfred (May 1922) President, Amsler-Morton Co, Inc, 720 Fulton Bldg; h, 1512 Westfield St, Beechview, Pittsburgh, Pa..**Atlantic 8735**

Moses, Graham Lee (Associate) (Oct. 1925) Electrical Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 444 South Ave, Wilkinsburg, Pittsburgh, Pa.................**Brandywine 1500-Ext. 9147**

Motok, George Thomas (Associate) (Oct. 1926) Student in Metallurgy, Carnegie Inst. of Technology; h, Box 330, Carnegie Inst. of Technology, Pittsburgh, Pa..........................**Mayflower 2600**

Mott, William Elton (April 1910) Director, College of Engineering, Carnegie Inst. of Technology; h, 58 King Edward Apts, 4609 Bayard St, Pittsburgh, Pa..............................**Mayflower 2600**

Moyer, F. Hughes (April 1930) President, Mackintosh-Hemphill Co, Point Bldg; h, 6309 Jackson St, Pittsburgh, Pa........**Court 3862**

Mulert, Justus Louis (Associate Member) (June 1928) Engineer, Gulf Research Laboratories, 327 Craft Ave; h, 842 Washington Road, South Hills, Pittsburgh, Pa......................**Mayflower 1520**

Mullen, John L. (April 1906) President, John L. Mullen Construction Co, 602 Wabash Bldg; h, 2756 S. Bergman St, Pittsburgh, Pa..**Court 2186**

Mullin, John William (March 1930) United Engineering & Fdry. Co, Farmers Bank Bldg, Pittsburgh, Pa; h, McKee Hotel, McKeesport, Pa..**Atlantic 0863**

Mundo, Charles Joseph (Dec. 1926) Manufacturers' Representative, Union Trust Bldg; h, 2136 Beechwood Blvd, Pittsburgh, Pa..**Atlantic 4592**

Murray, John J. (March 1921) Div. Supt, Equitable Gas Co, 6119 Penn Ave; h, 4738 Bayard St, Pittsburgh, Pa.............**Hiland 6700**

Murto, Harry Charles, Jr. (Associate Member) (Nov. 1925) Salesman, Hillside Stone & Supply Co, P. O. Box 1753; h, 232 Hastings St, Pittsburgh, Pa......................................**Sterling 0800**

Mylrea, Thomas Douglas (Jan. 1929) Professor, Building Construction, Carnegie Inst. of Technology, 101 College of Industries Bldg; h, 4212 Saline St, Pittsburgh, Pa.......................**Mayflower 2600**

Nace, Robert R. (April 1924) Chief Engr, Maintenance of Way, Pennsylvania R. R, 324 Pennsylvania Station, New York, N. Y; h, 31 Parker Road, Elizabeth, N. J.

Nagin, H. (Associate Member) (Dec. 1928) Secy. and Genl. Mgr, The Tri-Lok Co, 5555 Butler St, Pittsburgh, Pa............**Fisk 2750**

Nation, Robert B. (**Associate Member**) (Oct. 1926) Sales Mgr, Monel Metal Dept, Williams & Co, Inc, 901 Pennsylvania Ave, N. S; h, 5599 Baum Blvd, Pittsburgh, Pa.......................... **Cedar 2980**

Neale, Arthur (Nov. 1928) Mining Engineer, 198 West Prospect Ave, Crafton, Pittsburgh, Pa............................ **Walnut 1085**

★**Neave, Andrew A.** (Sept. 1911) Vice Pres, Treadwell Engineering Co, Easton, Pa; h, 326 Porter St, Easton, Pa.

Neeld, A. D., Jr. (March 1919) President, Infusolite Co, Plum Point, Calvert Co, Md; h, Plum Point, Md.

Neely, Forest Hunter (March 1929) Sales Engr, Pennsylvania Crusher Co, 1445 Oliver Bldg, Pittsburgh, Pa; h, Sixth St, Patterson Heights, Beaver Falls, Pa................................ **Atlantic 0839**

Neill, Benjamin Elmer (June 1928) Chief Surveyor, Real Estate Dept, Philadelphia Co, 435 Sixth Ave, Pittsburgh, Pa; h, 350 N. Jefferson Ave, Canonsburg, Pa................................ **Grant 4300**

★**NEILSON, GEORGE HARRISON** (**Past President 1919**) (Feb. 1903) Vice Pres, Water Treatment Co. of America, Grant Bldg; h, 646 Maple Lane, Sewickley, Pa........................ **Atlantic 5490**

Nelms, George C. (**Associate Member**) (April 1927) President, Portable Lamp & Equipment Co, 405 Penn Ave; h, 6349 Douglas St, Pittsburgh, Pa....................................... **Atlantic 0515**

Nelms, Harvey J. (Jan. 1930) Genl. Supt, Crucible Fuel Co, Crucible, Greene Co, Pa; h, Crucible, Greene Co, Pa.

Nelson, Harry Lloyd (**Associate Member**) (Oct. 1929) Acting Pgh. Sales Agt. and Western Research Engr, United States Pipe & Fdry. Co, 412 Oliver Bldg; h, 855 Jackman Ave, Avalon, Pittsburgh, Pa. .... **Atlantic 0767**

Nelson, James Augustus (Dec. 1928) Contracting Engr, Steel Pipe Dept, Riter-Conley Works, McClintic-Marshall Co, 1213 Oliver Bldg; h, Arapahoe Road, Brookside Farms, S. H, Pittsburgh, Pa...... .... **Atlantic 2562**

Nelson, Ray F. (**Associate Member**) (Dec. 1927) Draftsman, Monongahela Rwy. Co, 1200 Century Bldg; h, 1328 Pocono St, Swissvale P. O, Pittsburgh, Pa................................. **Atlantic 5244**

Newbaker, E. J. (April 1929) Genl. Mgr, The Berwind-White Coal Mining Co, Windber, Pa; h, Windber, Pa.

Newcomer, D. A. (July 1922) Address unknown.

Newdick, Norton A. (June 1929) Vice Pres, The Coloder Co, Inc, 568 N. Fourth St, Columbus, Ohio; h, 1114 Wyandotte Road, Columbus, Ohio.

Newlon, John Hawker (Feb. 1930) Geologist, Philadelphia Co. & Affiliated Oil & Gas Companies, 435 Sixth Ave; h, 206 Cedar Blvd, Mt. Lebanon, Pittsburgh, Pa .... **Grant 3200**

Nicholls, John A. (Feb. 1926) Asst. Engr, Bureau of City Transit, City of Pittsburgh, City-County Bldg, Pittsburgh, Pa; h, 67 Euclid Ave, Sharon, Pa .... **Atlantic 3900**

★**Nichols, George William** (Oct. 1909) Partner, Webb Engineering Co, Designing & Construction Engineers, 801 Oliver Bldg; h, 136 Jefferson Drive, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 0265**

Nichols, John Thayer (Oct. 1930) Physicist, American Sheet & Tin Plate Co, 210 Semple St; h, 803 S. Negley Ave, Pittsburgh, Pa .... **Mayflower 3110**

Nicholson, John Hancock (Feb. 1901) Vice Pres. In Charge of Sales, National Tube Co, 1827 Frick Bldg; h, 1515 Shady Ave, Pittsburgh, Pa .... **Atlantic 2500**

Nicol, George S. (**Associate**) (March 1930) Dist. Mgr, McClave-Brooks Co, Oliver Bldg; h, 939 Sheridan Ave, Pittsburgh, Pa .. **Atlantic 1799**

Niemann, Charles Franklin (**Associate**) (Oct. 1925) President, The Parkersburg Iron & Steel Co, 2003 Union Bank Bldg; h, 200 S. Linden Ave, Pittsburgh, Pa .... **Court 1311**

Nimick, Alexander (March 1926) Chief Engr, Colonial Steel Co, 324 Fourth Ave, Pittsburgh, or Monaca, Pa; h, 301 Chestnut Road, Edgeworth, Sewickley, Pa .... **Court 0582**

Noble, Albert G. (**Associate**) (March 1930) Salesman, E. I. DuPont de Nemours & Co, Clark Bldg; h, 551 S. Braddock Ave, Pittsburgh, Pa .... **Atlantic 7777**

Noble, Howard Agnew (Nov. 1915) President, Pittsburgh Spring & Steel Co, 1417 Farmers Bank Bldg; h, 1245 Shady Ave, Pittsburgh, Pa .... **Atlantic 1422**

Noble, Robert Elliott (Sept. 1912) Engineer, Rolling Mill Dept, Mesta Machine Co, West Homestead, Pa; h, 45 Home Ave, Crafton, Pittsburgh, Pa .... **Homestead 1080**

★**Norman, Fred** (May 1923) Chief Engr, Allegheny River Mining Co, Kittanning, Pa; h, 363 N. Jefferson St, Kittanning, Pa. **Kittanning 1026**

Norris, George L. (Jan. 1911) Chief Metallurgical Engr, Vanadium Corp, of America, 120 Broadway, New York, N. Y.

Norris, William H. (Feb. 1918) Ludlum Steel Co, Watervliet, N. Y; h, 630 Western Ave, Albany, N. Y.

Norton, Paul Thornley, Jr. (Jan. 1918) Professor of Industrial Engineering, Virginia Polytechnic Institute, Blacksburg, Va; h, Blacksburg, Va.

Nourie, Leonard R. (May 1923) Manufacturers' Agent, 722 Park Bldg; h, 741 Shady Drive East, Mt. Lebanon, Pittsburgh, Pa. . **Atlantic 3058**

Noyes, Maxwell E. (Oct. 1930) Sales Engr, Aluminum Co. of America, 2400 Oliver Bldg; h, 3405 Meadowcroft Ave, Mt. Lebanon, Pittsburgh, Pa. . . . . **Atlantic 4545**

Nuernberg, Arthur (June 1918) Genl. Supt. H. Miller & Sons Co, 2565 Fifth Ave, Pittsburgh, Pa; h, 822 Grant St, Turtle Creek, Pa. . . . . **Mayflower 5240**

O'Connor, Harry D. (Jan. 1916) Chief Engr, Pittsburgh Group, Columbia Gas & Electric Co, 800 Union Trust Bldg; h, 1835 Chellis St, N. S, Pittsburgh, Pa . . . . **Atlantic 9320**

Odell, John Dwight (Junior) (May 1926) Draftsman, The Koppers Construction Co, Koppers Bldg; h, 6304 Marchand St, Pittsburgh, Pa. . . . . **Atlantic 6240**

O'Donovan, James S. (May 1917) Chief Electrician, Spang-Chalfant & Co, Inc, Bridge St, Etna, Sharpsburg Sta; h, 410 Western Ave, Aspinwall, Pittsburgh, Pa . . . . **Sterling 0740**

Offutt, John W. (Feb. 1919) Asst. Genl. Supt, Ellwood Works, National Tube Co, Ellwood City, Pa; h, 301 Glen Ave, Ellwood City, Pa.

Olin, Otto (June 1924) Mech. Engr, Standard Seamless Tube Co, Ambridge, Pa; h, 1212 Ohioview Ave, Ambridge, Pa . . . . **Ambridge 380**

Olson, Harold M. (Feb. 1927) Dist. Mgr, The Permutit Co, 921 Union Trust Bldg; h, 171 Longue Vue Drive, Mt. Lebanon, Pittsburgh, Pa . . . . **Atlantic 4807**

Oppenheimer, Oscar W. (Associate) (Sept. 1930) President, Pittsburgh Steel Drum Co. and Secy-Treas, Apollo Steel Co, 2244 Oliver Bldg; h, 5831 Bartlett St, Pittsburgh, Pa . . . . **Atlantic 6312**

Orr, David Kirk (Feb. 1903) Supt, The Monongahela Railway Co, Brownsville, Fayette Co, Pa; h, 462 High St, S. Brownsville, Pa . . . . **Brownsville 840-1**

★**Orr, Newell Hamilton (Associate Member)** (June 1921) Contracting Engr, Jones & Laughlin Steel Corp, Junior Beam Div, Third & Ross St; h, 1408 Termon Ave, N. S, Pittsburgh, Pa . . . . **Court 3240**

Orr, Ralph Vincent (Associate) (May 1926) Sales Engr, E. W. Bliss Co, 1821 Guarantee Title Bldg, Cleveland, Ohio; h, 238 Cochran Road, Mt. Lebanon, Pittsburgh, Pa.

Orr, Thomas E. (Feb. 1924) Dist. Sales Mgr, American Gas Accumulator Co, 2882 W. Liberty Ave; h, 316 Parkway Drive, Mt. Lebanon, Pittsburgh, Pa . . . . **Lehigh 0600**

Orssten, Theodore (June 1928) Address unknown.

Osborne, Raymond Storms (Feb. 1930) Vice Pres, Industrial Paint Co, Oliver Bldg, Pittsburgh, Pa; h, Sewickley, Pa....... **Atlantic 2954**

Osbourne, Richard Barrows (Oct. 1929) Chief Engr, Phillips Mine & Mill Supply Co, 2227 Jane St, S. S; h, 248 Lebanon Ave, S. H, Pittsburgh, Pa.................................... **Hemlock 0130**

OSLER, GEORGE F. (Director) (Sept. 1925) President, Chartiers Creek Coal Co, 218 E. Pike St, Canonsburg, Pa; h, 916 Mellon St, Pittsburgh, Pa.................................. **Canonsburg 956**

Osler, Jay Thompson (May 1911) President, Continental Roll & Steel Fdry. Co, East Chicago, Ind; h, 20 Highland St, Hammond, Ind.

Ottinger, Harry (Feb. 1918) Designer, National Tube Co, McKeesport, Pa; h, 1308 Wilson St, McKeesport, Pa........ **McKeesport 21174**

Ousler, George Walter (Associate) (Dec. 1926) Manager, Rates and Retail Service, Philadelphia Co, 435 Sixth Ave; h, 2832 Shady Ave, Pittsburgh, Pa.................................... **Grant 4300**

Over, Raymond W. (Associate Member) (Dec. 1927) Dist. Rep, Pyott Foundry Co, Aetna Ball Bearing Mfg. Co, Benedum Trees Bldg, Pittsburgh, Pa; h, Haysville, Pa..................... **Court 3720**

Overton, Ralph M. (Oct. 1926) Asst. Power Engr, National Tube Co, 1606 Frick Bldg; h, 112 Atlanta Place, Mt. Lebanon, Pittsburgh, Pa... **Atlantic 2500**

Ow, Charles (Associate) (Oct. 1930) Clerk, Metallurgical Dept, Carnegie Steel Co, 559 Frick Annex Bldg; h, R. D. No. 7, Bellevue, Pittsburg, Pa............................... **Atlantic 5100-Ext. 7**

Owen, John E. (Feb. 1924) Steam Engr, Pittsburgh Steel Products Co, Monessen, Pa; h, 721 Broad Ave, Belle Vernon, Pa.. **Monessen 360**

Owen, Robert R. (Associate Member) (May 1930) Agent, General Electric Co, 40 Fourteenth St, Central Union Bldg, Wheeling, West Va; h, 109 Maple Ave, Wheeling, West Va.

Packard, G. Frederick (July 1911) Salesman, Equitable Life Insurance Society, 203 Frick Bldg, Pittsburgh, Pa; h, 182 Woodside Road, Wilkinsburg, Pittsburgh, Pa........................ **Atlantic 2800**

Pacy, Ernest H. (Associate Member) (April 1927) Pres. and Genl. Mgr. Pittsburgh Welding Corp, 33 Water St, Pittsburgh, Pa; h, Allison Park, Pa.................................... **Court 2068**

Paddock, L. A. (May 1928) Vice Pres, American Bridge Co, Frick Bldg; h, 1504 Denniston Ave, Pittsburgh, Pa............. **Atlantic 4300**

Palmer, Charles Douglas (June 1929) Engr. of Research, Pittsburgh Railways Co, 435 Sixth Ave; h, 220 Castle Shannon Road, Mt. Lebanon, Pittsburgh, Pa.................... **Grant 7450-Ext. 155**

Palmer, Charles Skeele, Ph. D. (Oct. 1918) Consulting Chemical Engineer; h, 4333 Dakota St, Schenley Heights, Pittsburgh, Pa. **Mayflower 9170**

Paret, Henry Wilbur, Jr. (April 1928) Manager, Burner Div, Swindell-Dressler Corp, P. O. Box 1753; h, Cathedral Mansions, Pittsburgh, Pa..**Sterling 1400**

Pargny, Eugene W. (June 1902) President, American Sheet & Tin Plate Co, 1322 Frick Bldg; h, 1054 Beechwood Blvd, Pittsburgh, Pa........ ....**Atlantic 1300**

Parker, Herbert E. (**Associate Member**) (June 1929) Draftsman, The Koppers Construction Co, Koppers Bldg; h, 55 N. Balph Ave, Bellevue, Pittsburgh, Pa...........................**Atlantic 6240**

Parkin, William Metcalf (Dec. 1903; March 1913) President, Wm. M. Parkin & Co, 1005 Highland Bldg; h, 5577 Hampton St, Pittsburgh, Pa..**Montrose 0176**

Parmelee, Earle Linsley (**Associate**) (Dec. 1922) Patent Attorney, Byrnes, Stebbins & Parmelee, 1717 Farmers Bank Bldg; h, 309 LeRoi Road, Pittsburgh, Pa...................................**Atlantic 1609**

Parry, William I. (June 1910) Engr. Salesman, Carnegie Steel Co, 227 Carnegie Bldg, Pittsburgh, Pa; h, 851 Thorn St, Sewickley, Pa. ....**Atlantic 5100-Ext. 313**

Parsons, Stanley J. (March 1917) Draftsman, H. C. Frick Coke Co, Scottdale, Pa; h, Dawson, Pa..........................**Scottdale 620**

Paschedag, Charles C. (May 1906) Dist. Supt, Service & Erection, Allis-Chalmers Mfg. Co, 815 Park Bldg; h, 2966 Voelkel Ave, Dormont, Pittsburgh, Pa...................................**Atlantic 1729**

Passmore, Henry E. (April 1927) Asst. to President, Verona Tool Works, Oakmont, Pa; h, 5668 Darlington Road, Pittsburgh, Pa........ ....**Oakmont 1000**

Patterson, Peter Charles (March 1892) Vice Pres, National Tube Co, 1712 Frick Bldg, Pittsburgh, Pa; h, 1901 Jenny Lind St, McKeesport, Pa....................................**Atlantic 2500**

Patterson, Robert F. (Oct. 1906) Mech. Engr, Keystone Driller Co, Beaver Falls, Pa; h, 1226 Sixth Ave, Beaver Falls, Pa...**Beaver Falls 69**

Patterson, William Joshua (Jan. 1921) Pres. and Genl. Mgr, Heyl & Patterson, Inc, 50 Water St; h, Schenley Apts, Pittsburgh, Pa..**Court 0753**

★**Paul, James W.** (Oct. 1913) Senior Mining Engr, U. S. Bureau of Mines, 4800 Forbes St; h, 619 S. Linden Ave, Pittsburgh, Pa. **Mayflower 4500**

Paulsen, William R. (Oct. 1926) Genl. Mgr, American Heat Economy Bureau, Inc, 928 Wabash Bldg; h, 2036 Wendover St, Pittsburgh, Pa..**Court 1744**

Peale, Rembrandt (March 1922) Engineer, Peale-Peacock-Kerr, Inc, St. Benedict, Pa.

Pearce, Leonard G. (Nov. 1924) Plant Engr, Pittsburgh Crucible Steel Co, Midland, Pa; h, 176 Taylor Ave, Beaver, Pa.......... **Midland 51**

Pearsall, Luther Thustin (Dec. 1919) Combustion Engr, Jones & Laughlin Steel Corp, S. S. Works, S. 27th & Carson Sts; h, 14 Oakwood Road, Crafton, Pittsburgh, Pa.................. **Hemlock 0401-Ext. 178**

Peat, D. Barr (**Associate Member**) (Dec. 1929) Vice Pres. and Asst. Treas, Issoudun Aviation Corp, Mid City Airport, Hudson, Ohio; h, Lock Box No. 12, Dravosburg, Pa.

Peden, John T. (April 1930) Manager, Steel Mill Section, Sales Dept, Westinghouse Electric & Mfg. Co, Grant Bldg; h, 3114 Iowa St, Pittsburgh, Pa.................................... **Atlantic 8400**

★**Peebles, Thomas A.** (May 1921) Vice Pres, Hagan Corp, 502 Bowman Bldg; h, 31 Mt. Lebanon Blvd, Mt. Lebanon, Pittsburgh, Pa.... .... **Court 4724**

Peirce, Charles L., Jr. (April 1923) President, Hubbard & Co, 6301 Butler St; h, 1424 Beechwood Blvd, Pittsburgh, Pa............ **Fisk 1333**

Peirce, W. Bradford (March 1923) Works Mgr, Pittsburgh Screw & Bolt Co, Graham Works, Neville Island, Pittsburgh, Pa; h, 219 Meadow Lane, Edgeworth, Sewickley, Pa.................... **Federal 1240**

★**Pendleton, Dudley D.** (Dec. 1911) Dist. Sales Mgr, Foster Wheeler Corp, 1439 Oliver Bldg; h, 1209 Wightman St, Pittsburgh, Pa. **Atlantic 2844**

Perkins, Thomas S. (Jan. 1901) Manager, Supply Engrg. Dept, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, Grey Hall, Irwin, Pa.. **Brandywine 1500**

Perrott, G. St. J. (Dec. 1927) Supt, Pittsburgh Experiment Station, U. S. Bureau of Mines, 4800 Forbes St; h, 5851 Morrowfield Ave, Pittsburgh, Pa................................. **Mayflower 4500**

Peters, F. G. (**Associate Member**) (May 1927) Sales Engr, H. H. Robertson Co, Grant Bldg, Pittsburgh, Pa; h, 927 Main St, Coraopolis, Pa. .... **Atlantic 3200**

Peterson, Harry Oscar (**Student Junior**) (June 1928) h, 248 S. 15th St, Sebring, Ohio.

Peterson, Victor Henry (Dec. 1926) Sales Engr, Elliott Co, 718 Frick Bldg; h, 5660 Munhall Road, Pittsburgh, Pa......... **Atlantic 5000**

Peth, Herbert William (Oct. 1927) Engineer, John F. Casey Co, P. O. Box 1753; h, 208 Eastern Ave, Aspinwall, Pittsburgh, Pa...... .... **Sterling 1400**

Pettay, George Theodore (March 1921) Member of Firm, Aires, Stone & Pettay, 6th Floor, 335 Blvd. of Allies; h, 3411 Terrace St, Pittsburgh, Pa..**Court 0128**

Pharo, Harry A. (Dec. 1924) President, Pharo Engineering Co, 517 Park Bldg; h, 600 North Ave, Wilkinsburg, Pittsburgh, Pa..**Atlantic 0888**

Phillips, Fernley Berrington (Student Junior) (Sept. 1927) Electrical Designer, Allis-Chalmers Mfg. Co, Columbus & Preble Sts, N. S, Pittsburgh, Pa; h, 113 East Genessee St, Etna, Pa.....**Cedar 1071**

PHILLIPS, FRANK REITH (Vice President) (Sept. 1913) Senior Vice Pres, Philadelphia Co, 435 Sixth Ave; h, 190 Orchard Drive, Mt. Lebanon, Pittsburgh, Pa...........................**Grant 7450**

Phillips, John M. (March 1898) President, Phillips Mine & Mill Supply Co, 2227 Jane St; h, 2336 Brownsville Road, Pittsburgh, Pa........ ....**Hemlock 0130**

Phillips, Leslie (Dec. 1926) Design Engr, Byllesby Engrg. & Management Corp, 435 Sixth Ave; h, 964 Jackman Ave, Avalon, Pittsburgh, Pa....................................**Grant 5750-Ext. 577**

Pierce, Lonnie J. (May 1917) Chief Engr, American Window Glass Co, 1622 Farmers Bank Bldg; h, 6649 Woodwell St, Pittsburgh, Pa. ....**Atlantic 0450**

Pigott, Reginald J. S. (June 1930) Staff Engr, Gulf Production & Pipe Line Cos, 327 Craft Ave; h, 312 Gladstone Road, Pittsburgh, Pa...... ....**Mayflower 1520**

Pinkerton, Andrew (Nov. 1907) Electrical Engr, American Sheet & Tin Plate Co, P. O. Box 427, 1115 Frick Bldg, Pittsburgh, Pa; h, 6605 Virginia Ave, Ben Avon, Pittsburgh, Pa.............**Atlantic 1300**

Pittman, Ernest Waller (Feb. 1903) Chief Engr, The Petroleum Iron Works Co. of Texas, P. O. Box 784, Beaumont, Texas; h, 2544 Calder Ave, Beaumont, Texas.

Polhemus, Dudley Abram (April 1912) Dist. Mgr, American Engineering Co, 2147 Oliver Bldg; h, 2703 Norwood St, Pittsburgh, Pa...... ....**Atlantic 2342**

Poling, Murray Yost (June 1929) Geodetic Engr, R. H. Randall & Co, 914 City-County Bldg; h, Ruskin Apts, Pittsburgh, Pa............ ....**Atlantic 3900-Ext. 277**

Polk, Robert Edmund (June 1919) Genl. Mgr, Equitable Sales Co, 427 Liberty Ave; h, 853 Taylor Ave, Avalon, Pittsburgh, Pa........ ....**Grant 3200-Ext. 279**

Porter, George, Jr. (Oct. 1923) Bureau of Water, City of Pittsburgh, 310 City-County Bldg; h, 420 Neville St, Pittsburgh, Pa............ ....**Atlantic 3900-Ext. 66**

Porter, Henry Tegmeyer (Oct. 1906) Chief Engr, Bessemer & Lake Erie R. R. Co, 160 Main St, Greenville, Pa; h, 334 Main St, Greenville, Pa.

Porter, Rudyard (Feb. 1924) Representative, American Sheet & Tin Plate Co, P. O. Box 62, Frick Bldg; h, 938 Bellefonte St, Pittsburgh, Pa. .... **Atlantic 1300**

Postlethwaite, Clarence E. (Feb. 1903) Asst. Vice Pres, Pressed Steel Car Co, 55 Broad St, New York, N. Y; h, 142 Hamilton Ave, New Rochelle, N. Y.

Pote, Kenneth E. (Associate Member) (June 1929) Dist. Mgr, Riley Stoker Corp, 1419 Farmers Bank Bldg; h, 259 Melwood St, Pittsburgh, Pa .... **Atlantic 0875**

Powel, Charles A. (Dec. 1926) Genl. Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 634 S. Linden Ave, Pittsburgh, Pa. .... **Brandywine 1500**

Powelson, Frank W. (June 1924) Civil Engr, Pressed Steel Car Co, Farmers Bank Bldg; h, 3065 Zephyr Ave, Pittsburgh, Pa ...... **Federal 0740**

Powers, Philip H. (Associate) (June 1930) Vice Pres, West Penn Power Co, 14 Wood St; h, 5808 Northumberland St, Pittsburgh, Pa .. **Court 4106**

Price, Philip Wallis (March 1915) Asst. Construction Engr, Bureau of Bridges, Dept. of Public Works, Allegheny County, 519 Smithfield St; h, 6950 Rosewood St, Homewood Sta, Pittsburgh, Pa .... **Atlantic 4900-Ext. 43**

Pringle, W. Dick (Associate Member) (Feb. 1925) Sales Engr, The W. S. Tyler Co. of Cleveland; h, 6648 Wilkins Ave, Pittsburgh, Pa. .... **Hazel 0219**

Provan, John Stevenson (Associate Member) (Feb. 1927) Junior Engr, Morris Knowles, Inc, 507 Westinghouse Bldg; h, 540 Seagirt St, Pittsburgh, Pa .... **Atlantic 3882**

Provost, George W. (Associate) (May 1912) President, Doubleday-Hill Electric Co, 110-12 Seventh St; h, 5808 Beacon St, Pittsburgh, Pa .... **Atlantic 3000**

Pryde, David (April 1911) Mgr. of Works, Superior Steel Corp, Carnegie, Pa; h, 19 Third St, Aspinwall, Pittsburgh, Pa ...... **Carnegie 23**

Pugh, George A. (Junior) (Feb. 1918) Vice Pres, The Aetna Standard Engrg. Co, Home Savings & Loan Bldg, Youngstown, Ohio; h, 353 E. Midlothean Blvd, Youngstown, Ohio.

Purcell, Thomas Edward (Jan. 1928) Genl. Supt. of Power Stations, Duquesne Light Co, 435 Sixth Ave; h, 5526 Wilkins Ave, Pittsburgh, Pa .... **Grant 4300-Ext. 218**

Quinn, Robert S. (Feb. 1928) Asst. Genl. Supt, Carnegie Steel Co, Mingo Junction, Ohio; h, 633 Lawson Ave, Steubenville, Ohio.

Rabberman, A. Leslie (Associate) (May 1924) Vice Pres. and Treas, Pennsylvania Drilling Co, 1812 W. Carson St; h, 3444 Universal St, Corliss Sta, Pittsburgh, Pa........................**Walnut 1783**

Ralston, William S. (Oct. 1904) Vice Pres, Chaplin-Fulton Mfg. Co, 36 Penn Ave; h, 6620 Kinsman Road, Pittsburgh, Pa......**Court 1201**

Ramsburg, Charles J. (June 1916) Vice Pres, The Koppers Co, 1650 Koppers Bldg, Pittsburgh, Pa; h, 5 East Drive, Edgeworth, Sewickley, Pa..**Atlantic 6240**

Ramsey, John Negley (May 1923) Partner, Vegeler Ramsey & Co, 208 Bowman Bldg; h, 6 Promenade St, Crafton, Pittsburgh, Pa.... ....**Court 4078**

Rankin, Harry Howard (April 1901; Sept. 1908) Practicing Civil Engr. and Land Surveyor, 309 Fourth Ave; h, 7012 Reynolds St, Pittsburgh, Pa..**Court 3628**

Rapp, Ralph Lehmer (Oct. 1925) 5005 Western Ave, Omaha, Neb.

Rassbach, Richard William (Dec. 1928) Mech. Engr., The Rust Engineering Co, Koppers Bldg; h, 5123 Center Ave, Pittsburgh, Pa. **Atlantic 8870**

Rawstorne, Charles Duren (Nov. 1930) Asst. to Vice Pres. and Genl. Mgr. of Sales, McClintic-Marshall Co, Oliver Bldg; h, 1259 Denniston Ave, Pittsburgh, Pa..............................**Atlantic 2562**

★**Rayburn, John M.** (March 1903; Sept. 1912) Civil and Mining Engr, 1115 House Bldg; h, 126 W. Prospect Ave, Ingram, Pittsburgh, Pa. ....**Court 3579**

★**RAYMER, ALBERT R. (Past President 1914)** (June 1902) Asst. Vice Pres. and Chief Engr, P&LE R. R. Co, P&LE Terminal Bldg, Pittsburgh, Pa; h, 258 Taylor Ave, Beaver, Pa.........**Court 3201**

Rederer, Benedict S. (Nov. 1912) Sales Mgr, Automatic Stoker Sales, Inc, 412 Plaza Bldg; h, 384 Avon Drive, Mt. Lebanon, Pittsburgh, Pa..**Atlantic 5096**

Reed, Chester A. (March 1928) Chief Combustion Engr, Pittsburgh Coal Co, 1026 Oliver Bldg; h, 28 Hazel Drive, Mt. Lebanon, Pittsburgh, Pa..**Atlantic 2181**

Reed, Louis J. (Feb. 1924) Asst. Chief Engr, Aliquippa Works, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 123 Orchard St, Aliquippa, Pa..**Aliquippa 101**

Reed, Van A., Jr. (Sept. 1924) Secy, Federal Engineering Co, 1420 Investment Bldg, 239 Fourth Ave, Pittsburgh, Pa; h, Elizabeth, Pa. ....**Court 2672**

★**Reed, William Edgar** (Jan. 1907) Consulting Engineer, 577 Union Trust Bldg; h, 5101 Fifth Ave, Pittsburgh, Pa.............**Atlantic 0478**

Rees, Thomas M. (Jan. 1880) President, James Rees & Sons Co, P. O. Box 709; h, 400 Morewood Ave, Pittsburgh, Pa........**Grant 0389**

Reese, David M. (March 1923) Designer, Carnegie Steel Co, Clairton, Pa; h, Mingo Road, R. D. No. 2, Finleyville, Pa....**Clairton 5 R-8**

Reich, Philip J. (May 1922) Div. Engr, American Bridge Co, 1424 Frick Bldg; h, 7006 Flaccus Road, Ben Avon, Pittsburgh, Pa..**Atlantic 4300**

Reilly, Louis D. (March 1928) Manager, Ambridge Plant, American Bridge Co, Ambridge, Pa; h, 526 Park Road, Ambridge, Pa..........**Sewickley 1003**

Reisinger, Horace W. (June 1918) Manufacturers' Agent, 710 Park Bldg; h, C-3 Alder Court Apts, 6112 Alder St, Pittsburgh, Pa..**Atlantic 1208**

★**Renkin, William O.** (Feb. 1916) Manager, Dry Quenching Equipment Corp, 200 Madison Ave, New York, N. Y; h, Elm & Center Sts, Oradell, N. J.

Renshaw, David E. (Oct. 1928) Mining Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 466 Cascade Road, Edgewood Acres, Wilkinsburg, Pittsburgh, Pa..............**Brandywine 1500**

★**Reppert, Charles M.** (June 1910) Chief Engr, Dept. Public Works, City of Pittsburgh, 418 City-County Bldg; h, 325 S. Dallas Ave, Pittsburgh, Pa..**Atlantic 3900**

Rice, Cyrus William (June 1922) President, Cyrus William Rice & Co, Inc, Water Purification Engineers and Chemists, Highland Bldg; h, 938 Farragut St, Pittsburgh, Pa................**Montrose 4239**

Rice, John M. (Feb. 1903; Dec. 1915) Consulting Engineer, Private Practice, 247 Oliver Bldg; h, 5425 Baywood St, Pittsburgh, Pa..**Atlantic 4738**

Rice, W. E. (**Associate Member**) (Feb. 1928) Associate Fuel Engr, Dept. of Commerce, U. S. Bureau of Mines, 4800 Forbes St; h, 1830 Beechwood Blvd, Pittsburgh, Pa................**Mayflower 4500**

Richards, Earl Morgan (Nov. 1925) Chief Industrial Engr, Aliquippa Works, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 307 Third St, Beaver, Pa....................................**Aliquippa 101**

Richardson, Charles Parker (**Associate Member**) (Oct. 1927) General Sales Dept, Dravo-Doyle Co. and Dravo Equipment Co, 300 Penn Ave; h, 310 Wood St, Pittsburgh, Pa..................**Court 5400**

Richardson, Joseph George (Sept. 1912) Civil Engineer; h, 2622 Norwood Ave, N. S, Pittsburgh, Pa..........................**Fairfax 6596**

Riddle, Lawrence Edward (March 1914) Genl. Supt, City Blast Furnace, Carnegie Steel Co, Isabella Furnaces, Sharpsburg, Pa; h, 717 Duquesne Blvd, Duquesne, Pa......................**Sterling 1500**

Riddle, Louis M. (**Associate**) (April 1928) Sales Engr, Ochiltree Electric Co, 505 Liberty Ave; h, 1459 Kelton Ave, Dormont, Pittsburgh, Pa..**Atlantic 1900**

Ridinger, Charles Wesley (Oct. 1896) President, Iron City Engrg. Co, Third Ave & Grant St. and Iron City Electric Co, 575 Sixth Ave; h, 5830 Marlborough St, Pittsburgh, Pa.............**Atlantic 9100**

Riegel, Clarence L. (**Associate**) (Oct. 1924) Asst. Dist. Auditor, General Electric Co, 120 Broadway, New York, N. Y; h, 212 Edgewood Terrace, South Orange, N. J.

★**Riegel, Ross Milton** (Oct. 1925) Departmental Designing Engr, Dept. Public Works, City of Pittsburgh, 420 City-County Bldg; h, 1132 Murrayhill Ave, Pittsburgh, Pa.....................**Atlantic 3900**

Rieger, William H. (Oct. 1924) Pgh. Sales Mgr, A. Finkl & Sons Co, 1326 Cortland St, Chicago, Ill; h, 212 Virginia Ave, Aspinwall, Pittsburgh, Pa..**Sterling 4785**

Riegler, L. J. (Nov. 1924) Asst. Engr, Pennsylvania R. R. Co, 1128 Pennsylvania Sta, Pittsburgh, Pa; h, 7028 Church Ave, Ben Avon, Pittsburgh, Pa.............................**Grant 6000-Ext. 94**

Riley, Albert Dowler (May 1918) Mech. Engr, Standard Chemical Co, Canonsburg, Pa; h, 42 Creighton Ave, Crafton, Pittsburgh, Pa. ....**Canonsburg 84**

Rinearson, R. W. (Dec. 1930) Vice Pres, A. M. Byers Co, Clark Bldg; h, 6619 Kinsman Road, Pittsburgh, Pa.............**Atlantic 8110**

Rinehart, Edward Everett (March 1921) Construction Supt, W. T. Grange Construction Co, 803 Keenan Bldg; h, 3401 Massachusetts Ave, N. S, Pittsburgh, Pa..........................**Atlantic 5754**

Ritchie, Julian (**Associate**) (May 1930) Asst. Mgr, E. I. du Pont de Nemours Co, 1912 Clark Bldg; h, 221 Magnolia Ave, S. H, Pittsburgh, Pa. ....**Atlantic 7777**

Rittman, Walter F. (Dec. 1926) Professor, Commercial Engineering, Carnegie Inst. of Technology; h, 12 Forbes Terrace, Pittsburgh, Pa.....................................**Mayflower 2600**

Ritts, Arch V. (June 1919) Chief Engr, Costello Engineering Co, 519 Oliver Bldg, Pittsburgh, Pa; h, Wyland Ave, Allison Park, Pa..**Atlantic 1493**

Ritts, William Henry (**Associate**) (April 1913) Steam Engr, Spang Chalfant & Co, Inc, Bridge St, Etna, Pa; h, 7 Pine St, Etna, Pa..**Sterling 0740**

Robbins, Charles (May 1921) Pres. and Treas, Robbins Electric Co, 830 Liberty Ave, Pittsburgh, Pa.........................**Atlantic 5900**

Roberts, George Braden (**Associate Member**) (Oct. 1929) Sr. Engr. of Design, Bureau of Bridges, Allegheny County, 519 Smithfield St; h, 2815 Voelkel Ave, Dormont, Pittsburgh, Pa..**Atlantic 4900-Ext. 44**

Roberts, Grant W. (Feb. 1929; Nov. 1929) Address unknown.

Roberts, James Milnor (Nov. 1914) Contracting Engr, McClintic-Marshall Co, Oliver Bldg; h, 168 Dickson Ave, Ben Avon, Pittsburgh, Pa. .... **Atlantic 2562**

Robertson, A. W. (Feb. 1929) Chairman of Board, Westinghouse Electric & Mfg. Co, 1923 Grant Bldg; h, R. F. D. No. 6, Brownsville and Fairhaven Roads, Mt. Oliver Sta, Pittsburgh, Pa.... **Atlantic 8400**

Robertson, David (Feb. 1927) Genl. Supt, Keystone Mining Co, East Brady, Pa; h, East Brady, Pa.......... **East Brady 39**

Robertson, Harold Hansard (Associate) (June 1918) President, H. H. Robertson Co, Grant Bldg; h, Park Mansions, Schenley Park, Pittsburgh, Pa.......... **Atlantic 3200**

Robertson, Ralph N. (Jan. 1927) Mech. Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 1100 Lancaster Ave, Pittsburgh, Pa.......... **Sterling 2700-Ext. 304**

Robey, Harry F. (Associate) (Oct. 1928) Industrial Engr, Aluminum Co. of America, 2400 Oliver Bldg; h, 416 Greendale Ave, Edgewood, Pittsburgh, Pa.......... **Atlantic 4545**

Robinson, John C. (Junior) (Sept. 1928) Draftsman, The Koppers Co, Koppers Bldg; h, 1250 S. Negley Ave, Pittsburgh, Pa.. **Atlantic 6240**

★**ROBINSON, J. FRENCH (Chairman Mineral Industries Section)** (Jan. 1925) Genl. Mgr, Lycoming Natural Gas Co, Engr. and Geologist, Peoples Natural Gas Co, 545 William Penn Way; h, 1849 Shaw Ave, Squirrel Hill, Pittsburgh, Pa.......... **Grant 5100**

Robinson, Mayes Randolph (Associate Member) (Dec. 1925) Sales Engr, Ventilating Equipment Co, Bessemer Bldg; h, 424 McCully St, Mt. Lebanon, Pittsburgh, Pa.......... **Atlantic 3181**

Rockwell, Willard Frederick (Dec. 1928) President, Pittsburgh Equitable Meter Co, 400 N. Lexington Ave; h, 140 W. Hutchinson Ave, Edgewood, Pittsburgh, Pa.......... **Churchill 8400**

Rodgers, Edward H. (Oct. 1904) American Sheet & Tin Plate Co, Farrell Works, Farrell, Pa; h, 1224 Washington St, Farrell, Pa. **Farrell 1200**

Rodgers, J. Franklin (June 1920) Sales Engr, 1409 Oliver Bldg; h, 1144 Wightman St, Pittsburgh, Pa.......... **Atlantic 2014**

Rodgers, W. P. (Dec. 1923) Civil and Mining Engineer, P. O. Box 564, Monongahela, Pa.......... **Monongahela 830**

Rodman, Clarence James (April 1929) Pres. and Treas, Steel Sanitary Co, Buckeye Jack Mfg. Co, Hill Top Oil Co, P. O. Box 869, Alliance, Ohio; h, 541 Overlook Drive, Alliance, Ohio.

Ross, Theodore H. (Sept. 1922) Dist. Mgr, Skinner Engine Co, 1409 Oliver Bldg; h, 1415 Hillsdale Ave, Pittsburgh, Pa......... **Atlantic 2014**

Roth, James Dorsey (Associate) (Dec. 1926) Valuation Engr, Philadelphia Co, 435 Sixth Ave; h, King Edward Apts, 4609 Bayard St, Pittsburgh, Pa............................... **Grant 4300-Ext. 595**

Rowland, Roger W. (Oct. 1926) President, New Castle Refractories Co, P. O. Box 193, New Castle, Pa; h, 1000 Highland Ave, New Castle, Pa.

Roy, R. J. (Associate Member) (Dec. 1928) Manager, Fairbanks Morse & Co, 1003 Law & Finance Bldg; h, 714 Wisteria Ave, Mt. Lebanon, Pittsburgh, Pa................................. **Atlantic 6761**

Royston, William Albert, Jr. (Associate) (May 1930) President, Royston Cadillac La Salle Co, 5607 Baum Blvd; h, Fox Chapel Road, Aspinwall, Pittsburgh, Pa........................... **Montrose 2300**

Rudd, Harold H. (Dec. 1926) Vice Pres, Railway and Industrial Engrg. Co, Greensburg, Pa; h, N. Westmoreland Ave, Greensburg, Pa. .... **Greensburg 1527**

Rugg, W. S. (Sept. 1924) Vice Pres, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, University Club, 123 University Place, Pittsburgh, Pa............................... **Brandywine 1500**

Ruhe, C. H. William (Nov. 1889) Supt. of Soldiers and Sailors Memorial Hall of Allegheny County, Fifth Ave & Bigelow Blvd; h, 1223 La Clair Ave, Swissvale, Pittsburgh, Pa........... **Mayflower 4253**

Rupp, Charles Henry (Associate) (April 1930) Asst. Treas, The Peoples Natural Gas Co, 545 William Penn Way; h, 6938 McPherson Blvd, Pittsburgh, Pa..................................... **Grant 5100**

Rush, Ralph M. (Feb. 1913) President, Rush Machinery Co. 3565 Bigelow Blvd; h, 1341 Heberton Ave, Pittsburgh, Pa........ **Schenley 7600**

Rust, Harry B. (June 1910) President, The Koppers Co, 1500 Koppers Bldg; h, 1177 Murrayhill Ave, Pittsburgh, Pa........ **Atlantic 6240**

Rust, Stirling Murray (May 1922) President, The Rust Engineering Co, Koppers Bldg; h, 1156 S. Negley Ave, Pittsburgh, Pa.. **Atlantic 8870**

Rust, William F. (Jan. 1925) Vice Pres, The Koppers Construction Co, Koppers Bldg; h, 1180 Murrayhill Ave, Pittsburgh, Pa.. **Atlantic 6240**

★**Ruud, Edwin** (Jan. 1888) President, Ruud Mfg. Co, 29th & Smallman Sts; h, 240 S. Graham St, Pittsburgh, Pa................ **Grant 6688**

Ryan, John T. (May 1921) Vice Pres. & Genl. Mgr, Mine Safety Appliances Co, Cor. Braddock Ave. & Thomas Blvd; h, 120 S. Richland Lane, Pittsburgh, Pa......................... **Churchill 5900**

Rys, C. F. W. (April 1910) Asst. to Pres. and Metallurgical Engr, Carnegie Steel Co, 517 Carnegie Bldg; h, 5463 Aylesboro Ave, Pittsburgh, Pa..**Atlantic 5100**

Sachs, William Albert (Associate Member) (Oct. 1930) Designing Engr, American Bridge Co, 1612 Frick Bldg; h, 1004 Evergreen Ave, Millvale, Pittsburgh, Pa........................**Atlantic 4300**

Saeger, Geoff A. (May 1927) Chemical Engr, Missouri Portland Cement Co, 1010 Pine St, St. Louis, Mo; h, 7417 Delmar Blvd, St. Louis, Mo.

Sanford, H. Starkey (Jan. 1903) Mgr. of Sales, Riter Conley Co, 39 Broadway, New York, N. Y; h, Kew Gardens Inn, Kew Gardens, Long Island, N. Y.

Sangdahl, George Stanley (March 1928) Manager, Cleveland Office, Chicago Bridge & Iron Works, 1126 Midland Bank Bldg, Cleveland, Ohio; h, 22299 Calverton Road, South Euclid, Ohio.

Sanville, Walter F. (Associate Member) (May 1922) 411 Blvd. of Allies; h, Schenley Arms Apts, Pittsburgh, Pa...............**Court 4262**

Saurbrey, Henry Alexis d'Origny (Associate Member) (May 1926) Chief Engr, Mellon-Stuart Co, 2112 Oliver Bldg, P. O. Box 1114; h, 5865 Alderson St, Pittsburgh, Pa.......................**Atlantic 0803**

Sborigi, Guido V. (Dec. 1926) President, Taylor-Wilson Mfg. Co, McKees Rocks, Pa; h, 86 King Edward Apts, Bayard St, Pittsburgh, Pa. ....**Federal 0171**

Schade, Charles G. (Sept. 1892) Chief Engr. and Works Mgr, Fort Pitt Bridge Works, Canonsburg, Pa; h, 215 Smithfield St, Canonsburg, Pa.....................................**Canonsburg 27**

Schaller, Robert H. (Associate Member) (May 1923) Supt, By-Product Coke Plant, Aliquippa Works, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 708 Hall St, Aliquippa, Pa..**Aliquippa 101-Ext. 13**

★**SCHARFF, MAURICE R. (Silver Medal 1920)** (Jan. 1913) Consulting Engr, Main & Co, First National Bank Bldg; h, 26 Gladstone Road, Pittsburgh, Pa..............................**Atlantic 3156**

Schatz, Fred C. (May 1901) Asst. Mgr, Joseph Horne Co, 501 Penn Ave; h, 741 Broughton St, Pittsburgh, Pa.................**Court 3000**

SCHAUER, FRANK F. (Director) (May 1924) Vice Pres. and Genl. Mgr, Equitable Gas Co, 435 Sixth Ave; h, 1454 Shady Ave, Pittsburgh, Pa..................................**Grant 7600-Ext. 55**

Scheib Walter H. (June 1922) Sales Engr, Tate Jones & Co, Inc, 519 Oliver Bldg; h, 353 Marshall Ave, N. S, Pittsburgh, Pa.....**Atlantic 1493**

Schein, Nathan (May 1922) Div. Engr, City of Pittsburgh, 419 City-County Bldg; h, 1341 Shady Ave, Pittsburgh, Pa....**Atlantic 3900**

Schenck, Rand Gilmore (**Associate Member**) (Oct. 1927) Sales Engr, Fiske Bros. Refining Co, Cheswick, Pa; h, Cheswick, Pa........ .... **Springdale 343**

Schiller, William B. (Jan. 1921) Retired; h, 5075 Forbes St, Pittsburgh, Pa.

Schisano, Charles F. (June 1930) Aeronautic Engineer, Bank of America Trust Co, Chamber of Commerce Bldg; h, Cathedral Mansions, Pittsburgh, Pa.................................. **Grant 3410**

Schmitz, Edwin H. (March 1928) Dist. Mgr, Riley Stoker Corp, 1419 Farmers Bank Bldg; h, 5660 Munhall Road, Pittsburgh, Pa...... .... **Atlantic 0875**

Schneider, Reinhold (March 1917) Chief Engr, Farrell & Sharon Works, Carnegie Steel Co, Farrell, Pa; h, 334 E. State St, Sharon, Pa.

Schneider, Robert A. (April 1921) Civil Engr. and Land Surveyor, 2706 Brownsville Road, Carrick, Pittsburgh, Pa........... **Carrick 0895**

SCHUCHERT JOSEPH S. (**Chairman Illuminating Engineers' Section**) (Dec. 1926) Supervisor, Lighting Sales, Duquesne Light Co, 435 Sixth Ave; h, 3000 Clermont Ave, Brentwood, Pittsburgh, Pa..... .... **Grant 4300**

Schuchman, Bertram F. (June 1912) Treasurer, Homestead Valve Mfg. Co, P. O. Box 278, Homestead, Pa; h, Homestead, Pa.......... .... **Homestead 1701**

Schultz, Ferdinand George (**Associate**) (Sept. 1929) Proprietor, Ferdinand G. Schultz Co, Mill and Fdry. Eqpt, 1125 Park Bldg; h, 215 Questend Ave, Mt. Lebanon, Pittsburgh, Pa......... **Atlantic 1607**

Schultz, Herbert A. (Oct. 1928) Manufacturers' Agent, 310 Plaza Bldg; h, 410 Bucknell St, Pittsburgh, Pa.................. **Atlantic 0147**

Schulze, Arthur R. (Oct. 1908) Asst. Chief Engr, Mingo Works, Carnegie Steel Co, Mingo Junction, Ohio; h, 300 South Bend Blvd, Steubenville, Ohio.

★**SCOTT, CHARLES FELTON** (**Past President 1902**) (April 1890) Professor of Electrical Engineering, Sheffield Scientific School of Yale University; h, 19 Trumbull St, New Haven, Conn.

Scott, J. Walter (March 1925) Senior Conduit Inspector, The Bell Telephone Co. of Penna, 416 Seventh Ave; h, 315 S. Fairmount Ave, Pittsburgh, Pa.................................. **Official 0050**

Scott, Maxwell William (Oct. 1924) Manager, Penn Machinery & Eqpt. Co, 2138 Oliver Bldg; h, 5928 Walnut St, Pittsburgh, Pa. **Atlantic 2274**

Scott, Samuel A. (Dec. 1902) Vice Pres. and Genl. Mgr, The New River Co, MacDonald, West Va; h, MacDonald, West Va.

Scott, Warren Randolph (April 1924) Consulting Engineer, 240 Sherman Ave, Canton, Mass.

★**Seaver, Kenneth** (May 1910) Vice Pres, Harbison-Walker Refractories Co, Farmers Bank Bldg, Pittsburgh, Pa; h, Hulton Road, Oakmont, Pa..**Atlantic 0942**

See, Theodore S. (July 1917) LaSalle Field Co, Hammond, Ind; h, 1321 Malvern Ave, Pittsburgh, Pa.

Seidle, Norman R. (Associate) (Dec. 1924) h, 207 Alden Road, Carnegie, Pa..**Carnegie 309-M**

Seipp, Henry C. (March 1929) Sales Engr, Art Metal Construction Co, 315 Oliver Bldg; h, 153 Morewood Ave, Pittsburgh, Pa. **Atlantic 1734**

Seldon, Henry William (April 1912) Supt, United Alloy Steel Corp, Canton Ohio; h, 1316-10th St, N. W, Canton, Ohio.

Selkirk, William Marshall (Dec. 1920) Chief Engr, Seamless Tube Div, Pittsburgh Steel Co, Monessen, Pa; h, 725 Broad Ave, North Belle Vernon, Pa..............................**Monessen 360**

Selquist, Rolf (Nov. 1929) Electrical Engr, Copperweld Steel Co, Glassport, Pa; h, El Tower Hotel, 5800 Munhall Road, Pittsburgh, Pa......................................**Brandywine 1320**

Severn, Arthur B. (March 1925) Genl. Mgr, A. Stucki Co, 419 Oliver Bldg; h, 1201 Chelton Ave, Dormont, Pittsburgh, Pa......**Atlantic 1250**

Shaw, George M. (Jan. 1903) Sales Rep, Standard Steel Car Co, P. O. Box 248, Baltimore, Md; h, 922 University Parkway, Baltimore, Md.

Shaw, Hugh Campbell (Associate) (June 1921) President, Shaw-Perkins Mfg. Co, 1643 Oliver Bldg; h, 2200 Beechwood Blvd, Pittsburgh, Pa..**Atlantic 2044**

Shaw, Norman Lowrie (Nov. 1907) Draftsman, The Koppers Construction Co, Koppers Bldg; h, 568 Orchard Ave, Bellevue, Pittsburgh, Pa..**Atlantic 6240**

★**Shaw, William** (Nov. 1921) Engineer, Freyn Engineering Co, Naberejnaya, Krasnogo Flota, Leningrad, U. S.-S. R.

Shepherd, Alexander Boteler (Feb. 1903) Second Vice Pres, Monongahela Connecting R. R, Third & Ross St; h, 420 Emerson St, Pittsburgh, Pa..**Court 3241**

Sherratt, Gayle F. (May 1925) Dist. Mgr, Chain Belt Co. of Milwaukee, Wis, 706 Magee Bldg; h, 6537 Wilkins Ave, Pittsburgh, Pa...... ....**Court 1430**

Shipley, Grant B. (Dec. 1912) President, Century Wood Preserving Co, 3010 Koppers Bldg; h, 5398 Hobart St, Pittsburgh, Pa..**Atlantic 4955**

Shiras, MacGilvray (May 1902) Ore Agent, Carnegie Steel Co, 820 Carnegie Bldg; h, 5746 Aylesboro Ave, Pittsburgh, Pa. . . **Atlantic 5100**

Shirk, William Blottenberger (Nov. 1928) Steel Mill Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 504 Ave "D", Wilkinsburg, Pittsburgh, Pa. . . . . **Brandywine 1500**

Shoffstall, Arthur S. (Sept. 1922) Genl. Mgr, The International Nickel Co, P. O. Box 1570, Huntington, West Va; h, 535-11th Ave, Huntington, West Va.

Shook, John Edward (Oct. 1923) Sales Engr, Foster Wheeler Corp, 1439 Oliver Bldg; h, 5 Main St, Mt. Oliver Sta, Pittsburgh, Pa. . . . . **Atlantic 2844**

Shotton, Bruce Gillespie (Oct. 1927) Dist. Sales Mgr, Hendrick Mfg. Co. of Carbondale, Pa, 1846 Koppers Bldg; h, 235 Academy Ave, Mt. Lebanon, Pittsburgh, Pa. . . . . **Atlantic 1648**

★**Shover, Barton Roy** (May 1921) Consulting Engineer, 441 Oliver Bldg; h, 4733 Wallingford St, Pittsburgh, Pa. . . . . **Atlantic 1893**

Shriner, Edward Coleman (Associate) (May 1922) Sales Engr, Consolidated-Ashcroft-Hancock Co, Inc, 1411 Park Bldg; h, 1710 Potomac Ave, Dormont, Pittsburgh, Pa. . . . . **Atlantic 6330**

Shrom, William G. (Nov. 1911; Jan. 1923) Jones & Laughlin Steel Corp, Aliquippa, Pa; h, 109 Shaw St, Aliquippa, Pa. . . . . . **Aliquippa 101**

Shuman, Jesse J. (April 1907) Inspecting Engr, Jones & Laughlin Steel Corp, Third & Ross St; h, 931 Sheridan Ave, Pittsburgh, Pa. . . . . **Court 3240**

Shupe, H. Parker (Associate) (Dec. 1924) Electrician, P. P. Robinson Co, Inc; h, 5834 Ellsworth Ave, Pittsburgh, Pa. . . . . **Montrose 7659**

Siefers, George Francis (April 1921) Civil Engr, G. F. Siefers Co, 541 Wood St; h, 210 Biddle Ave, Wilkinsburg, Pittsburgh, Pa. . . . . **Atlantic 3824 & Churchill 0494**

Sieffert, Ralph W. (Associate Member) (April 1930) Experimental Work, Industrial Research, 850 Broadhead Road, Aliquippa, Pa; h, 1316 Wade St, Aliquippa, Pa.

★**Siemon, Edward A.** (May 1930) Div. Genl. Supt, Hillman Coal & Coke Co, First National Bank Bldg, Pittsburgh, Pa; h, 404 Park St, California, Pa. . . . . **Atlantic 2620**

Simons, E. S. (June 1927) President, Pittsburgh Reflector Co, 400 Bowman Bldg; h, 513 Hill Ave, Wilkinsburg, Pittsburgh, Pa. . **Court 0571**

Simpson, T. Leslie (Associate Member) (May 1930) Salesman and Field Rep, The American Cast Iron Pipe Co. and The Scranton Pump Co, 406 Empire Bldg; h, 1023 Grandview Ave, Pittsburgh, Pa. . . . . **Atlantic 3438**

Sinclair, Carroll Taylor (**Associate**) (Dec. 1926) Elec. Engr, Transmission & Distribution, Pittsburgh Branch, Byllesby Engrg. & Management Corp, 435 Sixth Ave; h, 5457 Bartlett St, Pittsburgh, Pa. .... **Grant 5750-Ext. 544**

Sipe, Charles Allen (March 1926) Industrial Engr, Jones & Laughlin Steel Corp, Aliquippa, Pa; h, Y. M. C. A, Coraopolis, Pa.......... **Aliquippa 101**

Sivitz, William I. (June 1929) Dist. Engr, The Duriron Co, Inc, Dayton, Ohio, 922 Empire Bldg, Pittsburgh, Pa; h, 1630 Duffield St, Pittsburgh, Pa.......... **Atlantic 4149**

★**SKINKLE, WILLIAM BALDWIN** (**Director**) (July 1910) Engineer, Pittsburgh District Power Committee, Subsidiary Companies of United States Steel Corp, 1228 Frick Bldg, Pittsburgh, Pa; h, 912 Ridge Ave, Coraopolis, Pa.......... **Atlantic 1300**

Skinner, Charles Edward (Nov. 1903) Asst. Director of Engineering, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, Elmore Road, Wilkinsburg, Pittsburgh, Pa.......... **Brandywine 1500**

Skinner, Orville Campbell (Dec. 1896) Works Mgr, Standard Steel Works Co; h, "Open Hearth," Burnham, Pa.

Slater, Homer B. (May 1920) Engineer, The Koppers Construction Co, Koppers Bldg; h, 2922 Glenmore Ave, S. H, Pittsburgh, Pa.......... **Atlantic 6240**

Sleeman, Earl Carlton (Feb. 1913) Chief Engr, Detroit Seamless Steel Tubes Co, West Warren and Wyoming Ave, Dearborn, Mich; h, 7232 Kingsley Ave, Dearborn, Mich.

Slocum, Roy L. (May 1917) Supt, Universal Atlas Cement Co, Universal, Pa; h, 1120 Lancaster St, Pittsburgh, Pa.......... **Unity 8**

Sloman, Morley S. (May 1923) Dist. Mgr, Sullivan Machinery Co, 704 Eighth Ave, Huntington, West Va; h, 401-11th Ave, Huntington, West Va.

Smith, Albert (**Associate Member**) (Dec. 1927) Mining Engr, Graff Interests, Blairsville, Pa; h, Saltsburg, Pa.

Smith, DuRay (Dec. 1927) Supt, Union Spring & Mfg. Co, New Kensington, Pa.

Smith, Ethelbert W. (March 1930) Vice Pres, Central Region, Pennsylvania R. R. Co, 909 Pennsylvania Station; h, 5621 Northumberland St, Pittsburgh, Pa.......... **Grant 6000**

Smith, Harold Whitmore (Dec. 1924) Sales Mgr, Generating Apparatus, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 510 Pitt St, Wilkinsburg, Pittsburgh, Pa.......... **Brandywine 1500**

Smith, Howard Wells (Dec. 1920) Chief Engr, The Aetna Standard Engineering Co, Youngstown, Ohio; h, P. O. Box 545, Ellwood City, Pa.

Smith, Hubert P. (Jan. 1914) Director of Rates, Duquesne Light Co, 435 Sixth Ave, Pittsburgh, Pa; h, 145 Allegheny Ave, Emsworth, Pittsburgh, Pa .... **Grant 4300**

Smith, J. Hammond (Nov. 1903) Professor Civil Engineering, University of Pittsburgh; h, 6363 Douglas St, Pittsburgh, Pa . . . **Mayflower 3500**

Smith, John Hayes (May 1902; April 1922) Consulting Engineer, Harrisburg, Pa; h, 2609 Market St, Camp Hill, Cumberland County, Pa.

Smith, Newton Guy (July 1916) Engineer, Contracting Dept, Fort Pitt Bridge Works, Oliver Bldg; h, 44 Oakwood Road, Crafton, Pittsburgh, Pa .... **Atlantic 0654**

Smith, Peter Marshall (Associate) (Oct. 1919) Dist. Mgr, Treadwell Engineering Co, 2126 Farmers Bank Bldg; h, 101 Lawncroft Ave, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 2883**

Smith, Russell (May 1911) Mech. Supt, Pressed Steel Car Co, McKees Rocks, Pa; h, 19 N. Bryant Ave, Bellevue, Pittsburgh, Pa .... **Federal 0740**

Smith, Thomas Walter (Jan. 1909) Structural Engr, Carnegie Steel Co, 71 Broadway, New York, N. Y; h, 150 Sylvan St, Rutherford, N. J.

Smith-Peterson, N. O. (June 1923) Supt, Works, Sikorsky Aviation Corp, Stratford, Conn; h, 80 Buena Vista Road, Bridgeport, Conn.

Smitmans, John A. (Dec. 1910; July 1912) Address unknown.

Smoot, Charles H. (Jan. 1925) Pres. and Treas, Smoot Engineering Corp, 136 Liberty St, New York, N. Y; h, 40 Mountain Ave, Maplewood, N. J.

Snowden, Francis Laird, Jr. (Sept. 1915) Engineer, 153 Park Ave, Saranac Lake, N. Y.

Snyder, John Caspar (Associate Member) (May 1921) Salesman, Electric Controller & Mfg. Co, 1539 Oliver Bldg; h, 1901 Ovid Ave, Westwood, Crafton, Pittsburgh, Pa .... **Atlantic 4014**

Snyder, Lester Charles (Junior) (Nov. 1921) Chief Clerk, Fabricating Div, Jones & Laughlin Steel Corp, Third & Ross St; h, 704 N. Braddock Ave, Pittsburgh, Pa .... **Court 3240-Ext. 231**

Sommerfield, E. M. (Junior) (Jan. 1929) Mech. Engr, Rust Engineering Co, Koppers Bldg; h, 2305 Pioneer Ave, Pittsburgh, Pa. **Atlantic 8870**

Southard, Claude Frederic (Oct. 1922) Genl. Mgr, Duquesne Coal & Coke Co, 347 Oliver Bldg; h, 21 Main Entrance Drive, Lebanon Hills, Mt. Lebanon, Pittsburgh, Pa...................... **Atlantic 0902**

Southward, G. B. (April 1922) Mechanization Engr, American Mining Congress, 841 Munsey Bldg, Washington, D. C; h, The Fairfax, 2100 Massachusetts Ave, N. W, Washington, D. C.

Spain, Batt L. (March 1924) Mgr. Compressor Sales, General Electric Co, West Lynn, Mass; h, 87 Banks Road, Swampscott, Mass.

Speaker, Jay C. (April 1929) Partner, Speaker Contracting Co, 302 Commonwealth Annex Bldg; h, 325 McCully St, S. H, Pittsburgh, Pa.......................................**Court 1937**

Speer, J. Ramsey (June 1918) 509 Oliver Bldg; h, Wilderness Farms, Trappe, Talbot Co, Md..........................**Atlantic 2286**

★**Speller, Frank Newman** (March 1906) Director Metallurgy & Research Dept, National Tube Co, 1810 Frick Bldg; h, 6411 Darlington Road, Pittsburgh, Pa............................**Atlantic 2500**

★**SPELLMIRE, WALTER B. (Past President 1925)** (April 1917) Manager, General Electric Co, 1309 Oliver Bldg; h, 5701 Solway St, Pittsburgh, Pa...................................**Atlantic 6400**

Spencer, Elbert Roy (May 1919) Dist. Mgr, The Defiance Motor Truck Co; h, 828 E. Shiawassee St, Lansing, Mich.

Spencer, Howard F. (Junior) (Jan. 1926) Cadet Engr, The Rust Engineering Co, Koppers Bldg; h, 420 S. Lang Ave, Pittsburgh, Pa........ ....**Atlantic 8870**

Spilker, Henry P. (July 1907) President, Sterritt-Thomas Fdry. Co, 32nd & Smallman Sts; h, 1617 Jancey St, Pittsburgh, Pa...**Atlantic 6790**

Splane, Joshua G. (Dec. 1899) Vice Pres, Detroit Insulated Wire Co, Wesson Ave. & Albert St, Detroit, Mich; h, 439 E. Columbia St, Detroit, Mich.

Sprague, Norman Salisburg (April 1908; Jan. 1925) Consulting Engineer, Private Practice, 1011 Bessemer Bldg; h, 6372 Jackson St, Pittsburgh, Pa...................................**Atlantic 9518**

Sprecher, Clay (May 1905; March 1914) Sales Engineer, 1409 Oliver Bldg; h, 5 Highland Court, Callowhill St, Pittsburgh, Pa....**Atlantic 2014**

Staege, Stephen A. (Jan. 1928) Industrial Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 6624 Beacon St, Pittsburgh, Pa.............................**Brandywine 1500-Ext. 9388**

Stafford, Samuel A. (March 1928) Metallurgical Dept, Vulcan Crucible Steel Co, Aliquippa, Pa; h, 303 Chestnut Road, Edgeworth, Sewickley, Pa.......................................**Aliquippa 395**

Stafford, Samuel G. (April 1893) Vice Pres. and Genl. Mgr, Vulcan Crucible Steel Co, Aliquippa, Pa; h, 911 McIntyre Ave, Coraopolis, Pa. ....**Aliquippa 395**

★**Stahl, Karl F.** (April 1892) Consulting Chemist, 2318 Wharton St, S. S; h, 839 Chislett St, Pittsburgh, Pa................. **Hemlock 1173**

Stanton, Charles Beecher (Oct. 1913) Professor of Civil Engineering, Carnegie Inst. of Technology; h, Morrowfield Hotel, Pittsburgh, Pa.. **Mayflower 2600**

Starr, Arthur B., Jr. (Nov. 1915) Mftrs. Rep. & Partner, Starr-Carpenter, 1124 Park Bldg, Pittsburgh, Pa; h, R. D. No. 2, Coraopolis, Pa.. **Atlantic 1488-9**

Steber, Herman Louis (Junior) (Oct. 1929) Master Mechanic, Lewis Fdry. & Machine Co, Groveton, Pa; h, 710 Hiland Ave, Coraopolis, Pa. .... **Coraopolis 20**

Steidle, Edward (Feb. 1926) Dean, School of Mineral Industries, The Pennsylvania State College, State College, Pa; h, 323 East Hamilton Ave, State College, Pa.

Stephens, Wesley McKeown (Nov. 1912) Steam Engr, West Penn Power Co, Springdale, Pa; h, P. O. Box 227, Highland Ave, Cheswick, Pa.

Steuber, Milton C. (Associate Member) (Jan. 1928) Structural Designer, The Koppers Construction Co, Koppers Bldg; h, 1027 Macon Ave, Pittsburgh, Pa................................ **Atlantic 6240**

Stevens, Richard Harry (Nov. 1902) 5200 Springlake Way, Baltimore, Md.

Stevenson, Barton (Oct. 1924) Manager, Central Station Div, Westinghouse Electric & Mfg. Co, Grant Bldg; h, 5714 Elgin Ave, Pittsburgh, Pa.................................... **Atlantic 8400**

Stevenson, Harry Willis (Jan. 1904) Chief Engr, Nadine Pumping Station, Pennsylvania Water Co; h, Nadine, Pa, R. F. D. No. 1, Verona, Pa.. **Hiland 3063**

Stevenson, John Dickson (Jan. 1910) Chief Engr, Bureau of Bridges and Structures, 335 City-County Bldg; h, 1400 N. Highland Ave, Pittsburgh, Pa.................................. **Atlantic 3900**

Stevenson, Paul V. (Sept. 1906) Res. Mgr, Morse Chain Co, Westinghouse Bldg; h, 7124 Meade St, Pittsburgh, Pa............... **Grant 7290**

Stewart, James Ernest (June 1927) Hydraulic Engr, West Penn Power Co, 14 Wood St; h, 600 Highland Place, Bellevue, Pittsburgh, Pa. .... **Court 4106**

★**Stewart, Reid T.** (Dec. 1894) Prof. Mech. Engrg, University of Pittsburgh; h, 1524 Shady Ave, Pittsburgh, Pa............... **Mayflower 3500**

Stickle, Edward S. (April 1929) President, E. S. Stickle Co, 953 Union Trust Bldg; h, 5539 Fair Oaks St, Pittsburgh, Pa.... **Atlantic 5056**

Stiefel, R. C. (April 1915) Engineer, Ellwood City, Pa.... **Ellwood City 81**

Stockdale, Henry S. (Sept. 1923) Sales Engineer, 337 Oliver Bldg; h, 1682 Kelton Ave, Dormont, Pittsburgh, Pa . . . . **Atlantic 1504**

STOLTZ, GLENN E. (Director) (Dec. 1919) Manager, Industrial Engrg. Dept, Westinghouse Electric & Mfg. Co. East Pittsburgh, Pa; h, 151 W. Hutchinson Ave, Edgewood, Pittsburgh, Pa . . . . **Brandywine 1500**

Stone, Carleton Elijah (April 1921) Member of Firm, Aires, Stone & Pettay, 335 Blvd. of Allies, Pittsburgh, Pa; h, 702 Main St, Coraopolis, Pa . . . . **Court 0128**

Stone, Edmund Cushing (Oct. 1922) System Development Mgr, Duquesne Light Co, 435 Sixth Ave; h, Arlington Apts, 515 S. Aiken Ave, Pittsburgh, Pa . . . . **Grant 4300-Ext. 588**

STONE, LAUSON (Chairman Steel Works Section) (Dec. 1921) Asst. to President, Jones & Laughlin Steel Corp, 1109 J. & L. Bldg, Pittsburgh, Pa; h, 734 Fourth St, Beaver, Pa . . . . **Court 3240-Ext. 33**

Stone, Richard H. (Nov. 1925) Chemical Engr, The Vesuvius Crucible Co, Swissvale, Pa; h, 1222 Lancaster Ave, Swissvale, Pittsburgh, Pa . . . . **Brandywine 0107**

★**Storer, Norman W.** (April 1902) Consulting Railway Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 6818 Reynolds St, Pittsburgh, Pa . . . . **Brandywine 1500**

Stotz, Edward, Jr. (March 1922) Structural Engr, Edward Stotz, Architect, 801 Bessemer Bldg; h, 14 Hughes St, Ingram, Pa . . . . **Atlantic 1153**

Stotz, Norman I. (Associate) (Dec. 1927) Genl. Supt, Braeburn Alloy Steel Co, Braeburn, Pa; h, 426-10th St, Oakmont, Pa . . . **Tarentum 690**

Stow, Frederic Stevens (Associate Member) (March 1929) Resident Engr, The J. N. Chester Engineers, 813 Clark Bldg, Pittsburgh, Pa; h, 1310 W. 10th St, Erie, Pa . . . . **Atlantic 1140**

Stratton, William Cowper (Sept. 1910) Chief Engr, United States Coal & Coke Co, Gary, McDowell County, West Va.

Straub, Donald Benno (Junior) (Jan. 1929) Erection Dept, Fort Pitt Bridge Works, 2026 Oliver Bldg; h, 1120 Harvard Road, Thornburg, Pittsburgh, Pa . . . . **Atlantic 0654**

Straub, Theodore Alfred (July 1910) President, Electric Welding Co, 311 Ross St, Pittsburgh, Pa; h, 132 W. College St, Canonsburg, Pa . . . . **Court 2941**

Strickler, J. Harold (June 1924) Dist. Sales Mgr, Elliott Co, 718 Frick Bldg; h, 913 Miami Ave, Mt. Lebanon, Pittsburgh, Pa . . **Atlantic 5000**

Stroh, Charles Kirk (June 1928) Sanitary and Hydraulic Engr, The J. N. Chester Engineers, 813 Clark Bldg, Pittsburgh, Pa; h, 710 Beaver St, Sewickley, Pa . . . . **Atlantic 1140**

Strong, Carlton (Feb. 1925) Architect, Keystone Bldg, 324 Fifth Ave; h, 4731 Bayard St, Shadyside, Pittsburgh, Pa .... **Court 0965**

Stroup, Earle Clifford (Dec. 1927) Compressor Sales Engr, Chicago Pneumatic Tool Co, Room 200, 132 Seventh St; h, 1265 Wisconsin Ave, Dormont, Pittsburgh, Pa .... **Atlantic 4286**

★**Stuart, George Johnston** (March 1917) Engineer, Power Piping Society, 1608 Law & Finance Bldg; h, 306 S. Homewood Ave, Pittsburgh, Pa .... **Grant 3434**

Stuart, Gordon W. (**Associate Member**) (Sept. 1926) Div. Supt, Equitable Gas Co, 6404 Penn Ave; h, West Waldheim Road, Aspinwall, Pittsburgh, Pa .... **Hiland 6700-Ext. 1528**

Stuckeman, Herman Sydney (**Associate Member**) (May 1921) Union Barge Line Corp, Wabash Bldg; h, 3066 Pinehurst Ave, S. H. Pittsburgh, Pa .... **Court 1476**

★**STUCKI, ARNOLD** (**Past President 1915**) (**Treasurer**) (Dec. 1902) Consulting Engineer, Oliver Bldg; h, 42 N. Howard Ave, Bellevue, Pittsburgh, Pa .... **Atlantic 1250**

Studybaker, Aaron Daniel (June 1928) Bonus Dept, Monongahela Connecting R. R, 3540 Second Ave; h, 5324 Beeler St, Pittsburgh, Pa .... **Court 3240**

Sturges, Thomas B. (June 1918) President, Pennsylvania Drilling Co, 1205 Chartiers Ave; h, 3136 Pioneer Ave, Dormont, Pittsburgh, Pa .... **Walnut 1783**

Sutherland, William Chester (Jan. 1921) Vice Pres, In Charge of Manufacturing, Pittsburgh Steel Co, Union Trust Bldg; h, Hampton Hall, 166 N. Dithridge St, Pittsburgh, Pa .... **Atlantic 4760**

Svensson, Otto M. (**Associate**) (Feb. 1925) Engineer, Vanadium Corp. of America, Bridgeville, Pa; h, R. F. D. No. 3, P. O. Box 28, Bridgeville, Pa.

Swanberg, Floyd Ludwig (March 1926) Genl. Mgr, Kehota Mining Co, 706 First National Bank Bldg; h, 215 N. Homewood Ave, Pittsburgh, Pa .... **Atlantic 2311**

Swartz, Charles A. (**Associate**) (May 1928) Genl. Sales Mgr, Wilson Snyder Mfg. Co, First & Talbot Ave, Braddock, Pa; h, 1850 Shaw Ave, Pittsburgh, Pa .... **Brandywine 2913**

Swem, George A. (**Associate**) (Feb. 1930) Erection Engr, Permutit Co, 921 Union Trust Bldg; h, 435 Stanford Ave, West View, Pittsburgh, Pa .... **Atlantic 4807**

Sykes, Charles S. (**Associate**) (June 1930) Engineer, General Electric Co, Oliver Bldg; h, 447 Marietta Ave, S. H, Pittsburgh, Pa.. **Atlantic 6400**

Taber, George H., Jr. (Dec. 1916) Vice Pres, Sinclair Refining Co, 45 Nassau St, New York, N. Y; h, Manursing Ave, Rye, N. Y.

Tafel, Theodore, Jr. (**Associate Member**) (May 1921) Manager, Pittsburgh Works, Standard Sanitary Mfg. Co, 2801 Preble Ave; h, 7072 Woodland Road, Ben Avon, Pittsburgh, Pa......... **Linden 6070**

Taggart, R. S. (March 1926) Sales Rep, The Shelt Co. Inc, Elmira, New York; h, 214 LeMoyne Ave, Mt. Lebanon, Pittsburgh, Pa.

★**Tanner, J. Roy** (Sept. 1913) President, Pittsburgh Valve Fdry. & Construction Co, P. O. Box 1016; h, 5620 Elgin Ave, Pittsburgh, Pa...... .... **Atlantic 6630**

Tatom, Dan Evans (**Associate Member**) (Oct. 1930) Pipe Line & Welding Engr, Sales Dept, Linde Air Products Co, 101 Bowman Bldg, Third & Ross St, Pittsburgh, Pa; h, Glenshaw, Pa............ **Court 2155**

Taub, Edward S. (June 1925) Senior Engr, Morris Knowles Inc, 507 Westinghouse Bldg; h, Virginia & Zara Sts, Mt. Oliver Sta, Pittsburgh, Pa.. **Atlantic 3882**

Taylerson, Ewart Stanley (June 1924) Engr. of Tests, American Sheet & Tin Plate Co, 320 Frick Bldg; h, 733 Gallion Ave, S. H. Pittsburgh, Pa.. **Atlantic 1300**

Taylor, Charles Edward (May 1908) Civil and Mining Engineer, 5715 Solway St, Pittsburgh, Pa....................... **Schenley 0929**

Taylor, Clyde (April 1906) Sales Engr, Jones & Laughlin Steel Corp, Third & Ross St; h, 1431 Mervin Ave, Dormont, Pittsburgh, Pa. **Court 3240**

Taylor, David Edwin (May 1924) Mining Engr; h, Freeport, Pa........ .... **Freeport 207**

Taylor, E. H. (**Associate Member**) (April 1930) E. I. du Pont de Nemours & Co, Clark Bldg; h, 53 Division St, Crafton, Pittsburgh, Pa. .... **Atlantic 7777**

Taylor, Ernest Succop (Sept. 1922) Chief Engr, Pittsburgh Coal Co, 1012 Oliver Bldg; h, 5400 Darlington Road, Pittsburgh, Pa...... .... **Atlantic 2181**

Taylor, Harold Alexander (**Associate Member**) (Nov. 1914) Connecticut Mutual Life Insurance Co, 802 Union Bank Bldg; h, 7123 Meade St, Pittsburgh, Pa................................ **Court 5842**

Taylor, Norman C. (**Associate Member**) (April 1924) Draftsman, Montour Railroad Co, 1711 State Ave, Coraopolis, Pa; h, 9 Stanwood St, Crafton, Pittsburgh, Pa......................... **Coraopolis 72**

★**TAYLOR, SAMUEL ALFRED** (**Past President 1913**) (Jan. 1898) Consulting Engineer, Various Companies, 711 First National Bank Bldg; h, 617 Whitney Ave, Wilkinsburg, Pittsburgh, Pa...... **Atlantic 2311**

★**Templin, Richard Lawrence** (Jan. 1920) Chief Engr. of Tests, Aluminum Co. of America, Aluminum Research Laboratories, P. O. Box 77, New Kensington, Pa; h, 354 Riverview Drive, Parnassus, Pa. .... **New Kensington 2550**

Terman, Mark J. (Feb. 1926) Sales Engr, Babcock & Wilcox Co, 2730 Koppers Bldg; h, 247 Academy Ave,. Mt. Lebanon, Pittsburgh, Pa.. **Atlantic 0672**

Tew, John B. (Oct. 1927) Boro. Engineer, Baden Borough, P. O. Box 143, Baden, Pa; h, Rotteck & Milton St, Baden, Pa.

Thomas, Edgar A. (June 1924) Construction Foreman, Carnegie Steel Co, Homestead Steel Works, Munhall, Pa; h, Elizabeth, Pa.......... .... **Elizabeth 635-J**

★**Thomas, George P.** (Dec. 1908) President, Thomas Spacing Machine Co, 811 Fulton Bldg, Pittsburgh, Pa; h, Glenshaw, Pa.... **Atlantic 6459**

Thomas, George W. (Nov. 1924) Chief Engr, H. H. Robertson Co, 2000 Grant Bldg; h, 205 N. Homewood Ave, Pittsburgh, Pa.. **Atlantic 3200**

Thomas, P. C. (April 1930) Mgr. of Mines, The Koppers Coal Co, Koppers Bldg; h, 1930 Wightman St, Pittsburgh, Pa.......... **Atlantic 6240**

Thomas, Roger F. (**Associate Member**) (May 1927) 11 Audubon Road, Boston, Mass.

Thomas, Roy Emil (June 1929) Mftrs. Agent, Frank Adam Electric Co, Continental Electric Co, Motor Equipment Co, 1004 Law & Finance Bldg; h, 814 Ross Ave, Wilkinsburg, Pittsburgh, Pa.. **Atlantic 6453**

★**Thompson, John I.** (Dec. 1919) Vice Pres, The Koppers Construction Co, Koppers Bldg; h, Devon Lane, Ben Avon Heights, Bellevue P. O. Pittsburgh, Pa.................................. **Atlantic 6240**

Thorn, Thomas Holmes (Jan. 1920) Asst. Engr, The Chaplin-Fulton Mfg. Co, 36 Penn Ave; h, 120 Carnegie Place, Pittsburgh, Pa. .... **Court 1201**

Throm, Joseph H. (July 1917) Pgh. Mgr, David Lupton's Sons Co, 1624 Grant Bldg; h, 932 Jancey St, Pittsburgh, Pa........ **Atlantic 1814**

★**Tiemann, Hugh P.** (June 1911) Asst. Metallurgical Engr, Carnegie Steel Co, 563 Frick Bldg. Annex, Pittsburgh, Pa.......... **Atlantic 5100**

Tishlarich, Ottmar M. (June 1927) Engineer, A. M. Byers Co, Sixth & Bingham Sts, S. S; h, 230 W. Riverview Ave, Bellevue, Pittsburgh, Pa.. **Hemlock 1161**

Toler, James P. (March 1921) Mech. Engr, Pittsburgh Limestone Co, Johnson Bldg, New Castle, Pa; h, 1206 Albert St, New Castle, Pa.. **New Castle 404**

Tomlinson, John Edward (Jan. 1930) Chief Draftsman, Pittsburgh Coal Co, Oliver Bldg; h, 1515 Alton St, Pittsburgh, Pa........**Atlantic 2181**

Tone, S. L. (March 1891) h, 5305 Westminster Place, Pittsburgh, Pa. ....**Mayflower 5152**

Toner, Arthur Carlton (June 1917) Washington Mgr, Portland Cement Assn, 925 National Press Bldg, Washington, D. C; h, 2737 Devonshire Pl, N. W, Washington, D. C.

Totten, Johns McCleave (April 1924) Engineer, Griscom Russell Co, 304 Magnolia Bldg, Dallas, Texas.

Tower, Ellwood S. (Sept. 1927) Engineer, American Radiator Co, 310 Second Ave; h, 1411 Wightman St, Pittsburgh, Pa......**Court 4055**

Townrow, Frederick Wazney (Oct. 1924) Struct. Engr, The Koppers Construction Co, Koppers Bldg, Pittsburgh, Pa; h, 115 Smithfield St, Canonsburg, Pa..............................**Atlantic 6240**

★**Tracy, Louis D.** (Dec. 1920) Mining Engineer, 4 Forbes Terrace, Pittsburgh, Pa..................................**Schenley 2443**

Tracy, Stephen Jerome, Jr. (**Junior**) (April 1930) Instructor, University of Pittsburgh, 102 Thaw Hall; h, 3408 Iowa St, Pittsburgh, Pa. ....**Mayflower 3141**

Trax, Edward Carey (Oct. 1918) Chemical Engr, Water Dept, Filtration Plant, City of McKeesport; h, 1408 Centennial St, McKeesport, Pa....................................**McKeesport 22311**

Trayers, Edward B. (Sept. 1919) Draftsman, National Tube Co, McKeesport, Pa; h, 515 Pearl St, Duquesne, Pa........**McKeesport 21174**

Tredway, Alexander C. (**Associate Member**) (Dec. 1926) Designing Draftsman, City of Pittsburgh, City-County Bldg; h, 113 Hawkins Ave, N. S, Pittsburgh, Pa......................**Atlantic 3900-Ext. 191**

Trees, Joe Clifton (April 1924) Arkansas Natural Gas Co, Benedum Trees Bldg, Pittsburgh, Pa; h, Gibsonia, Pa................**Court 3765**

TRESCHOW, KENNETH F. (**Secretary**) (March 1924) Secretary, Engineers' Society of Western Pennsylvania, William Penn Hotel; h, 1332 Tennessee Ave, Dormont, Pittsburgh, Pa.......**Atlantic 9392**

Trexler, Edwin W. (Oct. 1921) Supt. Mechanical Dept, Bethlehem Steel Co, Johnstown, Pa; h, 514 Luzerne St, Johnstown, Pa.

Trimble, Alexander F. (Nov. 1922) Construction Engr, W. F. Trimble & Sons' Co, Genl. Contractors, 1719 Pennsylvania Ave, N. S; h, 82 N. Harrison Ave, Bellevue, Pittsburgh, Pa...........**Cedar 3280**

Trimble, John L. (**Associate Member**) (March 1926) Field Engr, Philadelphia Co, 435 Sixth Ave; h, 616 Copeland St, Pittsburgh, Pa. ....**Grant 4300-Ext. 550**

Trimble, Robert (Jan. 1880) Asst. Chief Engr, Pennsylvania R. R, Pennsylvania Station, Pittsburgh, Pa; h, Sewickley, Pa...**Grant 6000-Ext. 90**

★**Trinks, C. L. W.** (March 1901) Professor, Mechanical Engineering, Carnegie Inst. of Technology; h, 1410 Denniston St, Pittsburgh, Pa. ....**Mayflower 8946**

Truax, J. Charlton (March 1928) Sales Engr, Bertrand P. Tracy Co, 919 Fulton St, N. S; h, 1109 Arch St, N. S, Pittsburgh, Pa. **Fairfax 6536**

Truebe, Paul G. (Oct. 1923) Mech. Engineer, Gibsonia, Pa.

Turnbull, Thomas, Jr. (Oct. 1913) 835 Western Ave, N. S, Pittsburgh, Pa...**Fairfax 0452**

Turner, George Walter (Associate Member) (May 1929) Checker, Pittsburgh-Des Moines Steel Co, Neville Island, Pittsburgh, Pa; h, 629 George St, Coraopolis, Pa.........................**Federal 3000**

Tylee, Don O. (Dec. 1923) Steam Specialist, Westinghouse Electric & Mfg. Co, Grant Bldg; h, 223 Garland St, Edgewood, Pittsburgh, Pa..**Atlantic 8400**

Tyler, Lewis P. (Jan. 1919) Technical Mgr, Vacuum Oil Co, 717 Clark Bldg; h, 1317 Macon Ave, Pittsburgh, Pa............**Atlantic 8370**

Uhl, Elmer Jerry (Nov. 1919) Owner, Uhl Construction Co, 115 W. Fifth Ave, Homestead, Pa; h, 156 Oakview Ave, Edgewood, Pittsburgh, Pa.......................................**Homestead 1206**

Uhlinger, Roy H. (Oct. 1924) Chemical Engr, R. H. Uhlinger Laboratories, 2020 W. Liberty Ave; h, 462 Kenmont Ave, Mt. Lebanon, Pittsburgh, Pa...................................**Lehigh 4227**

Umstead, Elgie James (Jan. 1927) Div. Supt, Bureau of Water, City of Pittsburgh, 312 City-County Bldg; h, 2375 Fremont Place, Pittsburgh, Pa...................................**Atlantic 3900**

Undercoffler, William C. (March 1925) Works Mgr, Wyckoff Drawn Steel Co, Ambridge, Pa; h, 915 Maplewood Ave, Ambridge, Pa........ ....**Ambridge 446**

Unger, John S. (Feb. 1896) Manager, Research Bureau, Carnegie Steel Co, 1054 Frick Bldg. Annex; h, 5538 Aylesboro Ave, Pittsburgh, Pa. ....**Atlantic 5100**

Unkefer, Frederick D. (Jan. 1930) President, Unkefer Bros. Construction Co, 1322 Fulton Bldg; h, 45 N. Balph Ave, Bellevue, Pittsburgh, Pa...**Grant 5394**

Uptegraff, R. E. (June 1918; March 1924) Partner, Rutherford & Uptegraff, 1414 Clark Bldg; h, 1336 Penn Ave, Wilkinsburg, Pittsburgh, Pa...**Atlantic 9855**

Urquhart, George Copeland (May 1893) Genl. Agent, Real Estate Dept, Pennsylvania R. R, 512 Pennsylvania Station; h, 431 S. Atlantic Ave, Pittsburgh, Pa .... **Grant 6000-Ext. 300**

★**VanDeventer, Frank M.** (Dec. 1920) Mech. Engr, Construction Dept, Henry L. Doherty & Co, 60 Wall St, New York, N. Y; h, 645 St. Marks Ave, Westfield, N. J.

Van Pelt, Arthur A. (Feb. 1925) Sales Engr, Norma Hoffman Bearings Corp; h, 124 Virginia Ave, Aspinwall, Pittsburgh, Pa .. **Sterling 1933**

Van Sickel, Edward L. (**Associate Member**) (Dec. 1928) President, E. L. Van Sickel & Co, P. O. Box 265, Bradford, Pa; h, 103 Congress St, Bradford, Pa.

Venable, William Mayo (Nov. 1913) Manager, Development Dept, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 822 N. St. Clair St, Pittsburgh, Pa .... **Sterling 2700**

★**Vincent, Lewis** (May 1907) Vice Pres. and Chief Engr, Penn Bridge Co. of America, Beaver Falls, Pa; h, 255 Beaver St, Beaver, Pa .... **Beaver Falls 656**

Voelker, Aloys A. (Oct. 1914; June 1924) Structural Engr, The Koppers Co, 950 Koppers Bldg; h, 704 Clinton Ave, Bellevue, Pittsburgh, Pa .... **Atlantic 6240**

Vogel, Leo J. (March 1929) Manager, Interstate Equipment Corp, 506 Columbia Bank Bldg; h, 286 Magnolia Place, Mt. Lebanon, Pittsburgh, Pa .... **Court 2876**

Vollkommer, Josef (June 1905) Pres. and Genl. Mgr, Vitro Mfg. Co, 60 Oliffe St; h, 230 N. Fairmount St, Pittsburgh, Pa ..... **Federal 3550**

von Bernewitz, M. W. (Nov. 1930) Mining and Metallurgical Engr, U. S. Bureau of Mines, 4800 Forbes St; h, 6417 Kentucky Ave, Pittsburgh, Pa .... **Mayflower 4500**

Von Thaden, Herbert (June 1929) Vice Pres. and Genl. Mgr, Pittsburgh Metal Airplane Co, 1625 Island Ave, N. S; h, 312 McCully St, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 0816**

Wadsworth, Frank L. O. (Nov. 1899) Consulting Engineer, P. O. Box 5093, East Liberty Sta; h, 340 S. Highland Ave, Pittsburgh, Pa .... **Montrose 1511**

Wagenseil, Edgar W. (Nov. 1927) Sales Engr, Blaw-Knox Co, P. O. Box 915, Pittsburgh, Pa; h, 403 California Ave, Oakmont, Pa .... **Sterling 2700**

Waggoner, Russell E. (Oct. 1901) Manager, Morewood Gardens Apts, Inc; h, 1060 Morewood Ave, Pittsburgh, Pa ...... **Schenley 2457**

Wagner, Anthony (Jan. 1930) Sales Engr, American Bridge Co, 1431 Frick Bldg; h, 214 Waldorf St, N. S, Pittsburgh, Pa ... **Atlantic 4300**

Wakefield, H. E., Jr. (**Associate Member**) (April 1930) Sales Engr, Equitable Gas Co, 435 Sixth Ave; h, 735 N. Negley Ave, Pittsburgh, Pa. .... **Grant 7600**

★**Waldorf, Fred** (Sept. 1926) Dist. Mgr, Steel Mill Div, Timken Roller Bearing Co, 4925 Liberty Ave; h, 119 Gould Ave, N. S, Pittsburgh Pa .... **Mayflower 7200**

Waldschmidt, Howard Conrad (**Associate Member**) (Oct. 1927) Electrical Contractor, Glenfield, Pa; h, 360 Kilbuck St, Glenfield, Pa .... **Sewickley 1079-R**

Wales, Samuel Sigourney (April 1925) Chief Elec. Engr, Carnegie Steel Co, 1106 Carnegie Bldg; h, 471 S. Atlantic Ave, Pittsburgh, Pa .... **Atlantic 5100**

Walker, George J. (**Associate Member**) (May 1921) Contracting Engr, Heyl & Patterson, Inc, 52 Water St; h, 5729 Holden St, Pittsburgh, Pa .... **Court 0753**

Walker, J. W. (Jan. 1880) Chairman, Board of Directors, Duquesne Slag Products Co, 425 Commercial Trust Bldg, Philadelphia, Pa; h, Devon, Pa.

Wallace, William T. (May 1902) Vice Pres, South American Gulf Oil Co, 21 State St, New York, N. Y; h, 51 Cedar Drive, Great Neck, L. I., N. Y.

Wallace, William W. (March 1926) Sales Engr, Treadwell Construction Co, 2126 Farmers Bank Bldg; h, 350 Iroquois Place, Beaver, Pa. .... **Atlantic 2883**

Wallis, William B. (April 1921) President, Pittsburgh Electric Furnace Corp, Foot of 32nd St; h, 6714 McPherson Blvd, Pittsburgh, Pa. .... **Grant 6221**

★**Walter, Bruce** (Feb. 1903) Chief Engr, City Blast Furnaces, Carnegie Steel Co, Sharpsburg, Pa; h, 716 Sheridan Ave, Pittsburgh, Pa .... **Sterling 1503**

Walters, Richard E. (**Associate Member**) (April 1913; Nov. 1930) President, Bituminous Sales Co, 607 Mechanics Trust Bldg, Harrisburg, Pa; h, 1125 N. Front St, Harrisburg, Pa.

Walton, J. P. (Dec. 1927) Asst. Engr. of Bridges, Pennsylvania R. R, 1106 Penna. Station; h, 161 Oakview Ave, Edgewood, Pittsburgh, Pa .... **Grant 6000**

Walworth, Stanley L. (**Associate**) (Dec. 1926) Dist. Sales Mgr, Ohio Brass Co, 2044 Oliver Bldg; h, 7007 Flaccus Road, Ben Avon, Pittsburgh, Pa .... **Atlantic 1727**

Ward, Norman Brewer (March 1928) Financial Advisor, Piedmont Financial Co, 122 E. 42nd St, New York, N. Y; h, 20 Canterbury Road, Ben Avon, Pittsburgh, Pa.

Warden, William G. (Sept. 1925) Chairman of Board, Pittsburgh Coal Co, 1131 Oliver Bldg, Pittsburgh, Pa; h, "Red Gate" School Lane, Germantown, Philadelphia, Pa.................... **Atlantic 2181**

Warner, James Paul (Oct. 1925) Electrical Engr, Private Practice, 903 Century Bldg; h, 5350 Beeler St, Pittsburgh, Pa...... **Atlantic 2679**

Warren, George S. (Oct. 1911) Chief Engr, Sharon Steel Hoop Co, Sharon, Pa; h, 936 Alcoma St, Sharon, Pa.................. **Sharon 1910**

Warren, Raymond V. (May 1929) Engrg. Rep, Western Penna. Sand & Gravel Assn, 406 Empire Bldg; h, 22 S. Bryant Ave, Bellevue, Pittsburgh, Pa................................ **Atlantic 6348**

Waterman, Fred W., Sr. (March 1929) President, National Tube Co, Frick Bldg; h, Schenley Apts, Pittsburgh, Pa........ **Atlantic 2504**

Watson, Thomas Paul (Oct. 1925) Prin. Asst. Engr, Pennsylvania R. R. Co, Broad St. Sta, Philadelphia, Pa; h, 148 Edgehill Road, Bala, Pa.

Watkins, Donald N. (June 1927) Pres. and Genl. Mgr. Steel Publications, Inc, Thaw Bldg, 108 Smithfield St; h, 1500 Greenmont Ave, Dormont, Pittsburgh, Pa................................ **Court 1214**

Watt, Scott Nevin (Sept. 1922) Sales Engr, American Bridge Co, 1418 Frick Bldg, Pittsburgh, Pa; h, 228 Dalzell Ave, Ben Avon, Pittsburgh, Pa.................................... **Atlantic 4300**

Watts, Joseph (June 1920) Engineer, Box 219, Salem, Mass.

Weaver, George H. (**Associate Member**) (Sept. 1914) Plant Mgr, The Atlantic Refining Co, 5733 Butler St; h, Highland Terrace, O'Hara Township, Aspinwall, Pittsburgh, Pa.................. **Fisk 1361**

Weber, Karl B. (May 1917) Architect, Designer and Engr, City of Pittsburgh, Old City Hall, N. S; h, 413 Evergreen Ave, Pittsburgh, Pa.. **Cedar 0168**

Webster, J. E. (March 1930) Works Engr, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 523 N. Negley Ave, Pittsburgh, Pa. .... **Brandywine 1500**

★**Webster, T. Frank** (Sept. 1903) Mgr. Sales, Link Belt Co, Philadelphia, Pa; h, Cliveden Hall, Germantown, Philadelphia, Pa.

Webster, W. R. (Dec. 1927) Engineer, The Alan Wood Steel Co, Conshohocken, Pa; h, 2333 N. 17th St, Philadelphia, Pa.

★**Weidlein, Edward Ray** (March 1919) Director, Mellon Institute of Industrial Research, University of Pittsburgh, Chemist & Chemical Engr; h, 6549 Northumberland St, Pittsburgh, Pa.. **Mayflower 1100**

Weiland, George C. (April 1928) Secy. & Sales Mgr, Schaffer Poidometer Co, 2818 Smallman St; h, 412 Jucunda St, Pittsburgh, Pa........ .... **Altantic 9030**

Weimer, Wilbur G. (April 1921) Section Engr, Philadelphia Co, 435 Sixth Ave, Pittsburgh, Pa; h, 615 Ferree St, Coraopolis, Pa .... **Grant 3200-Ext. 550**

Weir, Ernest T. (Jan. 1921) President, Weirton Steel Co, Weirton, West Va; h, Schenley Apts, Pittsburgh, Pa .... **Mayflower 2044**

Weir, Paul Latimer (Dec. 1927) Junior Engr, Byllesby Engrg. & Management Corp, 435 Sixth Ave; h, 438 Franklin Ave, Wilkinsburg, Pittsburgh, Pa .... **Grant 5750-Ext. 552**

Weise, Paul H. (Jan. 1925) Engineer, South Fayette Coal Co, 530 Oliver Bldg, Pittsburgh, Pa; h, 539 Green St, South Brownsville, Pa.

★**Weldin, Wm. Archie** (May 1903) Member of Firm, Blum, Weldin & Co, Engineers & Surveyors, 417 Grant St; h, 1938 Beechwood Blvd, Pittsburgh, Pa .... **Court 4997**

Welker, Richard M. (**Associate**) (Jan. 1926) Lubricating Engr, Gulf Refining Co, 1256 Frick Bldg. Annex; h, 675 Washington Road, Mt. Lebanon, Pittsburgh, Pa .... **Atlantic 5300**

★**Wendt, Edwin Frederic** (April 1892; Jan. 1913) Consulting Engineer, Union Trust Bldg, Washington, D. C; h, 1470 Third Ave, New Brighton, Pa.

Wessel, Albert H. (Jan. 1928) Chief Engr, Bernard H. Prack, 509 Martin Bldg; h, 5846 Marlborough St, Pittsburgh, Pa .... **Fairfax 7841**

Westinghouse, Henry Herman (May 1902) Chairman, Westinghouse Air Brake Co, 150 Broadway, New York, N. Y.

Wharton, Joseph B. (April 1919) Chief Engr, Spang Chalfant & Co, Inc, Ambridge, Pa; h, P. O. Box 70, Ingomar, Pa .... **Ambridge 380**

Wharton, William Bakewell (**Associate Member**) (Sept. 1923) Patent Attorney, Farmers Bank Bldg; h, 1208 Murrayhill Ave, Pittsburgh, Pa .... **Atlantic 0386**

Wheeler, William Sprague (Dec. 1928) Vice Pres. and Treas, Pennsylvania Engrg. Works, New Castle, Pa; h, 301 Sheridan Ave, New Castle, Pa.

Whigham, William, Jr. (April 1923) Manager Marine Repair Dept, Dravo Contracting Co, Neville Island, Pittsburgh, Pa; h, 659 Delaware Ave, Wilson Station, Clairton, Pa .... **Federal 2600**

Whipple, Thomas T. (**Associate Member**) (Oct. 1930) Designer, Burrell-Mase Engrg. Co, 709 Law & Finance Bldg; h, 1216 Illinois Ave, S. H, Pittsburgh, Pa .... **Atlantic 2094**

★**White, Harry M.** (June 1928) Mgr. of Mines, Pittsburgh Coal Co, 1018 Oliver Bldg; h, 2922 Belrose Ave, S. H, Pittsburgh, Pa .. **Atlantic 2181**

★**White, Jerome C.** (Dec. 1928) Production Engr, Pittsburgh Coal Co, 1012 Oliver Bldg; h, 1416 Potomac Ave, Pittsburgh, Pa. **Atlantic 2181**

Whited, E. Willis (Dec. 1915) Director, Co-operative Work, University of Pittsburgh, 111 Thaw Hall; h, 7329 McClure Ave, Swissvale, Pittsburgh, Pa. . . . . **Mayflower 3500**

Whited, Willis (Jan. 1899) Advisory Bridge Engr, State Dept. of Highways, Harrisburg, Pa; h, 26 S. Third St, Harrisburg, Pa.

Whiter, Edward Taft (June 1925) Regional Vice Pres, Pennsylvania R. R. Co, 921 Penna. Station; h, Bellefield Dwellings, Pittsburgh, Pa. . . . . **Grant 6000-Ext. 240**

Whitwell, George E. (Dec. 1926) Vice Pres. In Charge of Sales, Duquesne Light Co, 435 Sixth Ave; h, 521 Glen Arden Drive, Pittsburgh, Pa. . . . . **Grant 4300-Ext. 212**

Wickerham, Philip Sheridan (Oct. 1925) Consulting Civil Engr, City of Butler, Central Fire Station, Butler, Pa; h, 339 N. McKean St, Butler, Pa. . . . . **Butler 24121**

Wiggins, William D. (June 1927) Chief Engr, Central Region, Pennsylvania R. R. Co, 1135 Penna. Station; h, 1128 Princeton Ave, Crafton, Pittsburgh, Pa. . . . . **Grant 6000-Ext. 90**

Wilcox, Frank (Jan. 1894) Engineer, Retired, 533 Fifth Ave, Pittsburgh, Pa; h, 214 Thorn St, Sewickley, Pa . . . . **Atlantic 0564**

Wilcoxson, Leslie Swales (Associate Member) (April 1924) Engineer, Babcock & Wilcox Co, 85 Liberty St, New York, N. Y; h, 191 Highwood Ave, Ridgewood, N. J.

★**Wilkerson, T. J.** (April 1903; Jan. 1925) County Engr, Private Practice, P. O. Box 444, 721—11th St, Beaver Falls, Pa; h, 3221 Sixth Ave, Beaver Falls, Pa . . . . **Beaver Falls 1450**

Willard, J. O. (Jan. 1925) Civil Engineer, 1232 Franklin Ave, Woodlawn, Pa.

Williams, Burdell Sandford (March 1930) Branch Mgr, York Ice Machinery Corp, 2400 Carson St; h, 2936 Mattern Ave, Dormont, Pittsburgh, Pa. . . . . **Hemlock 1480**

Williams, Charles Henry (Junior) (Jan. 1930) Engrg. Asst, Power Engineer's Office, National Tube Co, Frick Bldg; h, 332 Stratford Ave, Pittsburgh, Pa. . . . . **Atlantic 2500**

Williams, D. Curtis (May 1921) Mech. Engr, National Works, National Tube Co, 2222 Second Ave; h, 664 Maryland Ave, Pittsburgh, Pa. . . . . **Grant 1548**

Williams, E. M. (April 1930) Secy. and Treas, Standard Alloy Co, Inc, 1679 Collamer Road, Cleveland, Ohio; h, Hotel Olmsted, Cleveland, Ohio.

Williams, Frank Way (Associate Member) (May 1926) Sales Engr, Simplex Pile Foundation Co, Conestoga Bldg; h, 5409 Coral St, Pittsburgh, Pa. . . . . **Court 2247**

Williams, Harold E. (Dec. 1924) President, Williams & Co, Inc, 901 Pennsylvania Ave, N. S; h, 5128 Pembroke Place, Pittsburgh, Pa .... **Cedar 2980**

Williams, Homer D. (Jan. 1915) President, Pittsburgh Steel Co, P. O. Box 72, 700 Union Trust Bldg; h, 5605 Aylesboro Ave, Pittsburgh, Pa .... **Atlantic 4760**

Williams, Howard L. (Sept. 1920) President, Pittsburgh Wire Rope Co, Verona, Pa; h, 14 Washington Ave, Oakmont, Pa .... **Oakmont 157**

Williams, James Peter, Jr. (May 1925) Vice Pres, The Koppers Coal Co, 1050 Koppers Bldg; h, 621 S. Linden Ave, Pittsburgh, Pa .... **Atlantic 6240**

Williams, Marshall (Jan. 1903; March 1916) Asst. Genl. Operating Mgr, American Bridge Co, 1510 Frick Bldg; h, 6105 Howe St, Pittsburgh, Pa .... **Atlantic 4300**

Williams, Thomas McRae (Junior) (Dec. 1929) Technical Employee, American Telephone & Telegraph Co, 610 Smithfield St; h, 2533 Perrysville Ave, Pittsburgh, Pa .... **Official 0050-Ext. 442**

Wilson, Charles A. McKinley (Associate Member) (April 1926) Draftsman, Pittsburgh Coal Co, Preparation Dept, 8 Market St, Pittsburgh, Pa; h, 333 Tioga St, Homestead Park, Homestead, Pa .. **Atlantic 2181**

Wilson, Dean R. (Associate Member) (Feb. 1924) President, Industrial Finance & Investment Co, 829 Oliver Bldg; h, Fox Chapel Manor, Aspinwall, Pittsburgh, Pa .... **Atlantic 0840**

Wilson, Edward (April 1928) Sales Engineer, 318 Neville St, Pittsburgh, Pa.

Wilson, Henry Dalzell (July 1921) Clark Bldg, Pittsburgh, Pa; h, 1011 Oak Grove Ave, Pasadena, Cal .... **Atlantic 0353**

Wilson, Howard Mitchell (Associate Member) (Dec. 1926) Secy, Taylor-Wilson Mfg. Co, McKees Rocks, Pa; h, 3150 Avalon St, Pittsburgh, Pa .... **Federal 0171**

Wilson, Leonard J. (April 1906) Asst. Engr, Brier Hill Steel Co, Youngstown, Ohio; h, R. F. D. No. 2, Warren, Ohio.

Wilson, Robert Lee (May 1905) Asst. to President, Westinghouse Electric & Mfg. Co, East Pittsburgh, Pa; h, 5744 Kentucky Ave, Pittsburgh, Pa .... **Brandywine 1500**

Winder, Frank Joseph (Associate Member) (Nov. 1923) Research Engr, (Supt.) Surface Combustion Co, 2375 Dorr St, Toledo, Ohio; h, 3313 Kirkwall Road, Ottawa Hills, Toledo, Ohio.

Winkleman, Edward J. (April 1924) Chief Engr, Duquesne Slag Products Co, 808 Diamond Bank Bldg, Pittsburgh, Pa; h, 121 Washington Ave, Oakmont, Pa .... **Atlantic 3841**

Winslow, George W. (Feb. 1930) Manager, Ingersoll-Rand Co, 706 Chamber of Commerce Bldg; h, 917 Wellesley Road, Pittsburgh, Pa .... **Atlantic 9070**

Wisecarver, Timothy J., Jr. (Associate) (March 1929) Salesman, Aluminum Co. of America, 1618 Oliver Bldg; h, Webster Hall, Pittsburgh, Pa .... **Atlantic 4545**

Wisener, George Edward (June 1916) Genl. Supt, Carnegie Steel Co, Mingo Junction, Ohio; h, 1013 LaBelle Ave, Steubenville, Ohio.

Wishoski, I. Stanley (Associate Member) (March 1923) Managing Editor, "Fuels & Furnaces," F. C. Andresen & Associates, Inc, 511 Plaza Bldg; h, 313 Pennwood Ave, Wilkinsburg, Pittsburgh, Pa .... **Atlantic 5002**

Witherow, William Porter (Oct. 1910) Vice Pres, Republic Steel Corp, Fourth & Bingham Sts; h, 5448 Northumberland Ave, Pittsburgh, Pa .... **Hemlock 0740**

Witmer, Charles Kenneth (June 1920) Master Mechanic, Westmoreland Coal Co, Irwin, Pa; h, Penna. Ave. & Locust St, Irwin, Pa.

Witt, Charles Victor (Jan. 1907) President, Witt-Humphrey Steel Co, Greensburg, Pa; h, Greensburg, Pa .... **Greensburg 1460**

Wohlgemuth, M. J. (Jan. 1928) h, 1218 Morningside Ave, Pittsburgh, Pa .... **Emerson 0910**

Wood, Eric Fisher (Oct. 1921) Managing Partner, Eric Fisher Wood & Co, 233 Oliver Ave; h, 5848 Solway St, Pittsburgh, Pa .... **Atlantic 4075**

Wood, Frank Joseph (Dec. 1927) Engineer, Rolling Mill Dept, Mesta Machine Co, W. Homestead, Pa; h, 431 Layton Ave, Dormont, Pittsburgh, Pa .... **Homestead 1080**

Woods, Leonard G. (Jan. 1888) President, Union Spring & Mfg. Co, 2001 Clark Bldg; h, Hotel Schenley, Pittsburgh, Pa .... **Atlantic 3060**

★**Wooldridge, Charles Lawson** (April 1906) Consulting Engr, Charles L. Wooldridge, Inc, 1027 Fulton Bldg; h, 819 St. James St, Pittsburgh, Pa .... **Grant 4025**

Work, William Roth (June 1916; Jan. 1924) Professor, Electrical Engrg, Carnegie Inst. of Technology; h, 5702 Beacon St, Pittsburgh, Pa. .... **Mayflower 2600**

Worthington, Arthur Whittemore (Dec. 1927) Asst. to Genl. Mgr, Pittsburgh Limestone Co, 216 Carnegie Bldg; h, University Club, 123 University Place, Pittsburgh, Pa .... **Atlantic 5100**

Worthington, Harvey R. (Associate) (May 1924) Real Estate Broker, Harvey R. Worthington Co, 102 Vandergrift Bldg; h, 358 S. Highland Ave, Pittsburgh, Pa .... **Court 2956**

Wray, David Conden (Dec. 1928) Genl. Supt, American Zinc & Chemical Co, Langeloth, Pa; h, Langeloth, Pa.................. **Grant 3138**

Wunder, Edgar D. (Nov. 1928) Engineer, Pittsburgh Coal Co. Shops, Library, Pa; h, 1141 McNeilly Ave, S. H, Pittsburgh, Pa. **Library 52**

Wyant, Frank A. (April 1921) Carnegie Land Co, 357 Frick Bldg; h, 5520 Baum Blvd, Pittsburgh, Pa........................ **Atlantic 5100**

Wyrough, Clement J. (May 1925) Supt, Power Dept, South Side Works, Jones & Laughlin Steel Corp; h, 41 Marlin Drive, East, Mt. Lebanon, Pittsburgh, Pa............................... **Hemlock 0401**

Yardley, John Linn McKim (May 1921) Manager, Engrg. Div, Westinghouse Electric & Mfg. Co, Grant Bldg; h, 901 S. Negley Ave, Pittsburgh, Pa.................................... **Atlantic 8400**

Yohe, C. M. (March 1930) Vice Pres, The Pittsburgh & Lake Erie R. R. Co, Pittsburgh, Pa; h, 6665 Kinsman Road, Pittsburgh, Pa.. **Court 2581**

Yohe, James B. (June 1922) Retired Vice Pres, Pittsburgh & Lake Erie R. R. Co, 106 P. & L. E. Terminal Bldg; h, 87 King Edward Apts, Pittsburgh, Pa................................. **Court 5524**

Young, Charles A. (**Associate**) (Sept. 1923) President, Young Roadbuilders Co, 611 Farmers Bank Bldg; h, 32 Grant Ave, Bellevue, Pittsburgh, Pa.. **Atlantic 2917**

★**Young, Lewis E.** (Feb. 1927) Vice Pres, Pittsburgh Coal Co, P. O. Box 64, Oliver Bldg; h, Bldg. F, Schenley Apts, Pittsburgh, Pa.. **Atlantic 2181**

Young, P. Arthur (Sept. 1903; Nov. 1922) Material Inspector, Stone & Webster, 1184 Union Trust Bldg; h, R. F. D. No. 2, Bridgeville, Pa.. **Atlantic 4630**

Youngman, Robert Harper (**Associate Member**) (May 1915) Asst. to President, Harbison-Walker Refractories Co, 2216 Farmers Bank Bldg; h, 206 S. Linden Ave, Pittsburgh, Pa.............. **Atlantic 0942**

Zeeryp, H. C. (**Associate Member**) (Nov. 1923) Dist. Mgr, Otis Elevator Co, 406 Chamber of Commerce Bldg; h, 1222 Lancaster St, Regent Square, Pittsburgh, Pa......................... **Atlantic 9292**

Zelditch, Morris (March 1928) Manufacturers' Agent, 212 Fitzsimmons Bldg, 331 Fourth Ave; h, 2301 Lutz Ave, Carrick, Pittsburgh, Pa... **Court 1852**

Zimmerman, Rufus Eicher (March 1924) Asst. to Vice Pres, American Sheet & Tin Plate Co, 1320 Frick Bldg; h, 300 S. Linden Ave, Pittsburgh, Pa................................ **Atlantic 1300**

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McInerney, W. I.

Millvale
Burns, S. H.
Lyon, J. A.
Sachs, W. A.

Monessen
Chartener, V.

Monongahela City
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Rodgers, W. P.

Morrisville
Malmstrom, U. W.

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Bisler, W. E.
Blake, A. W.
Bloom, F. S.
Bohn, D. I.
Boyle, W. W.
Butt, F. H.
Chew, R. E.
Cole, H. F.
Cooke, M. W.
Culbertson, A. L.
Cundy, O. R.
Daum, A. E.
Denigan, E. P.
Elliott, B. K.
Ewald, R. F.
Ewalt, D. S.
Fawcett, W. H.
Freeman, P. J.
Garratt, F.
Godard, R. S.
Gregg, L. O.
Haggart, C. N.
Haller, F. E.
Herrmann, J. L.
Hill, H. O.
Hoeveler, J. A.
Hoffman, W. G.
Homer, W. E.
Johnson, A. B.
Judy, E. W.
Kaltenbach, E. G.
Keogh, J. K.
Kuhman, L. F.
Laboon, J. F.
Laird, J. B.
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Nichols, G. W.
Nourie, L. R.
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Olson, H. M.
Orr, R. V.
Orr, T. E.
Osbourne, R. B.
Overton, R. M.
Palmer, C. D.
Peebles, T. A.
Phillips, F. R.
Rederer, B. S.
Reed, C. A.
Robinson, M. R.
Schultz, F. G.
Shotton, B. G.
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Uhlinger, R. H.
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Von Thaden, H.
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Wyrough, C. J.

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Oursler, J. S.

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Herrman, T. J.
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Koch, C. S.
Malseed, W. H.
Ottinger, H.
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Trax, E. C.

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Clement, A. E.

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Mali, F. F.
Wendt, E. F.

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Rowland, R. W.
Toler, J. P.
Wheeler, W. S.

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Lytle, W. O.
Smith, D.

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Boothman, D. M.
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Winkleman, E. J.

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Loftus, P. F.
Logan, H. M.
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Lyon, D.
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McCullough, F. M.
McCullough, W. T., Jr.
McCune, W. H.
McDaniel, B. P.
McEwen, J. A.
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McGovern, T. J.
McIntire, T. B.
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McKean, R. A.
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McKinley, J.
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McMillen, A. K.
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McMillin, O. B.
McNaugher, D. W.
McNeil, D.
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McQuiston, W. B.
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Odell, J. D.
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Paret, H. W., Jr.
Pargny, E. W.
Parkin, W. M.
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Paul, J. W.
Paulsen, W. R.
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Peirce, C. L., Jr.
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Perrott, G. St. J.
Peterson, V. H.
Pettay, G. T.
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Piggott, R. J. S.
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DESIGN AND PERFORMANCE OF WATER-COOLED FURNACES*

By P. N. Oberholtzer†

This paper, despite its broader title, is limited to the use of water cooling with underfeed stoker-fired furnaces.

During the past few years there has been a decided tendency in this country and abroad to increase capacities of steam-generating units in both public utilities and industrial plants. Along with this development of increased capacities there has been a decided increase in the use of water-cooled furnaces; so much so, in fact, that the use of water cooling has become almost standard practice in furnace design.

The principal reason for installing water-walls is to increase capacity, regardless of whether the water cooling results in actual increase in steam generation under existing conditions or whether it permits the boiler units to maintain the same output with poorer grades of coal.

The development of water-walls has been more gradual than is realized. About seven or eight years ago water cooling was first applied only to the rear wall of the ash-pit of stoker-fired boilers.

The Grand Rapids plant of the Consumers Power Company was, it is believed, the first installation making use of a water-back located in the rear wall of the ash-pit, its purpose being to aid in the discharge of refuse and to prevent the adhesion of clinkers and slag at this point.

The next development in design of water cooling consisted of extended water-walls covering large areas, but unfortunately this water cooling was not located in the furnace where the need was greatest. The design of these furnaces neglected to provide protection for that portion of the furnace which was really vital to the satisfactory operation of the stoker.

Another factor influencing the development of water cooling was the necessity, with some types of firing, for the prevention of

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†American Engineering Co., Philadelphia.

slag formation on the furnace walls. This brought out the question of completely water-cooled furnaces.

At about the same time, increased furnace volumes were being considered and, with the extensive amount of refractory required for such furnaces, it was believed that water cooling would prove more economical. This, then, brought about the question of the cost of such water cooling and its relation to the total cost of the entire boiler unit.

An analysis of the conditions encountered in the operation of the boiler unit might well be made here to see what benefits, other than increased capacity, result from the use of water cooling.

First, water cooling, properly located, provides protection in the furnace walls along the fire line adjacent to the fuel bed of the stoker to prevent the adhesion of slag and the consequent erosion produced by the moving fuel bed.

Second, the increased volumes of the furnaces required extensive refractory walls and their maintenance added greatly to the cost of operation of the boiler units. Water-walls were therefore installed to replace that part of the furnace brickwork which received the hardest service, and at the same time to provide a construction that would endure and be capable of supporting the remaining refractory portion of the furnace walls.

Another requirement of water-walls, which is very important and should not be overlooked, is the ability to provide access and observation doors which are conveniently located without requiring costly water-wall construction.

A typical installation of water cooling is shown in Fig. 1. With water-cooled rear walls a block-covered section is required, extending down into the crusher pit. It is a very simple matter, and costs very little more, to extend the water-wall tubes the entire height of the rear wall as shown in this installation. This obviates the necessity of introducing brickwork in the rear wall, the only brickwork required being that between the boiler and the top of the water-wall.

In the side wall it is necessary to extend the water cooling to a sufficient height to prevent the adhesion of slag, to prevent flame impingement and to prevent erosion, caused by the moving fuel bed.

Fig. 2 shows the method of supporting the water-wall shown in Fig. 1. This illustration shows the triangular-shaped blocks located

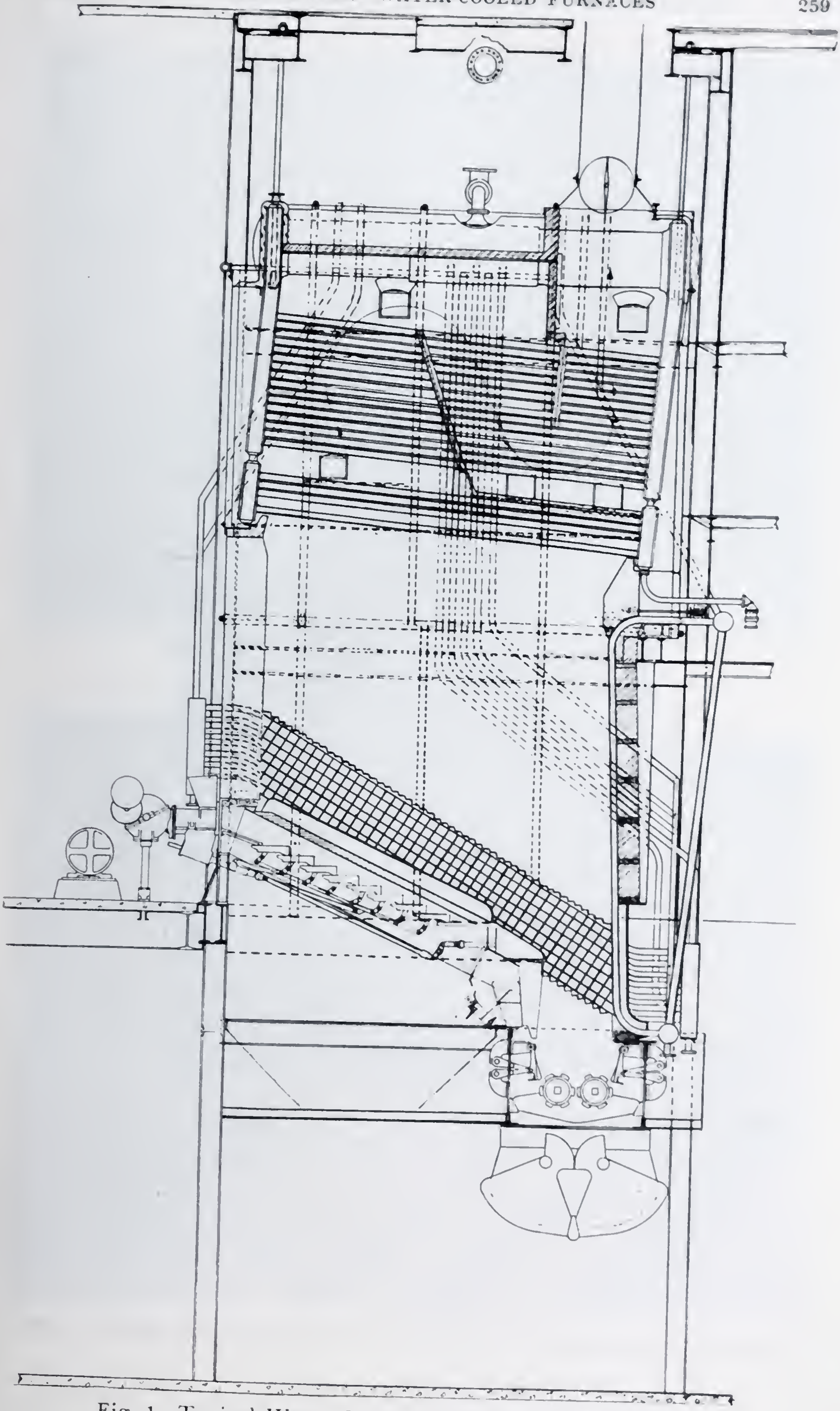


Fig. 1. Typical Water-Cooled Furnace for Stoker Firing.

upon the inclined members forming the supporting framework upon which the brickwork is built up. Similar blocks are fastened to the lower inclined supporting member, providing the necessary step-like projections for bricking up the furnace wall below the water-wall.

The type of water-wall construction illustrated in Fig. 1 has been used very extensively in stokers burning Pittsburgh, West Vir-

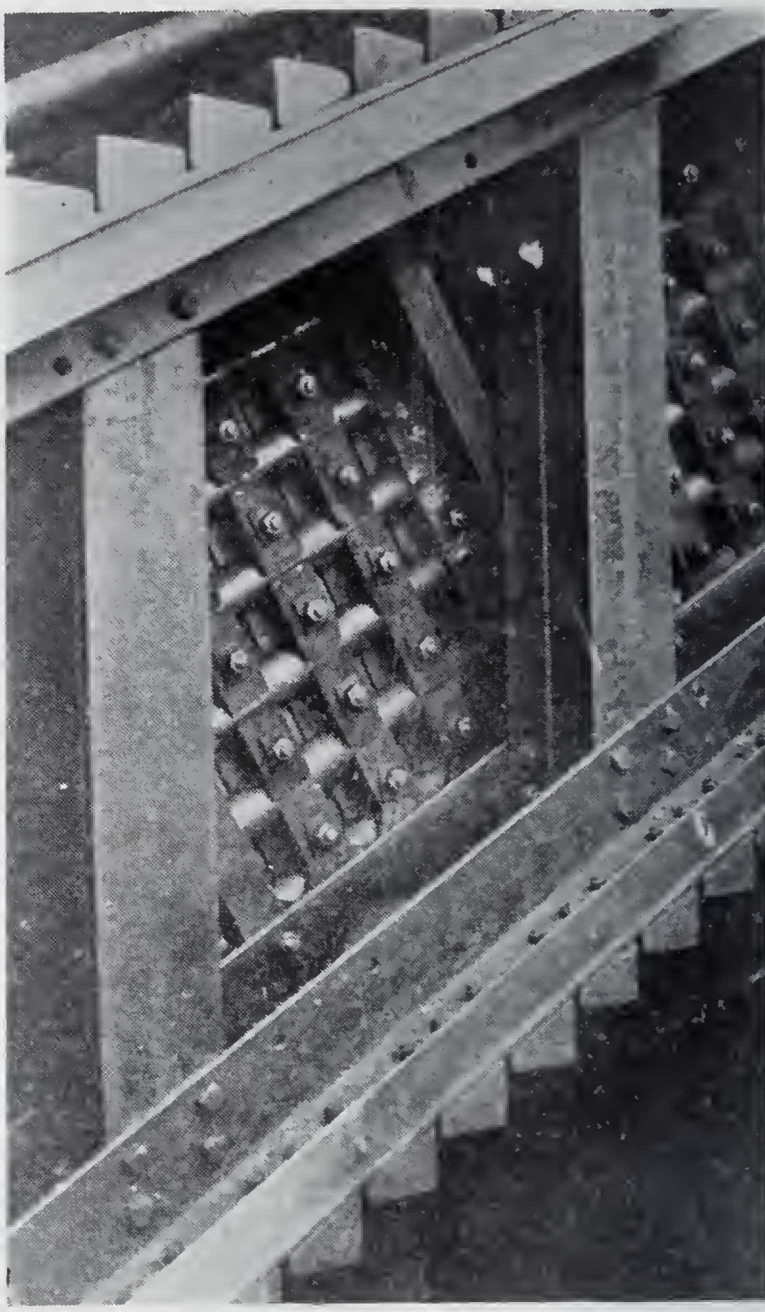


Fig. 2. Side Water-Wall Supporting Structure.

ginia, and Ohio coals. Also, at moderate ratings this same construction has been used in furnaces burning Indiana, Iowa, and other coals having high sulphur content and low ash-fusion temperature. Further experience, however, indicated that, under more severe operating conditions and higher fuel-burning rates, the coals having low fusion

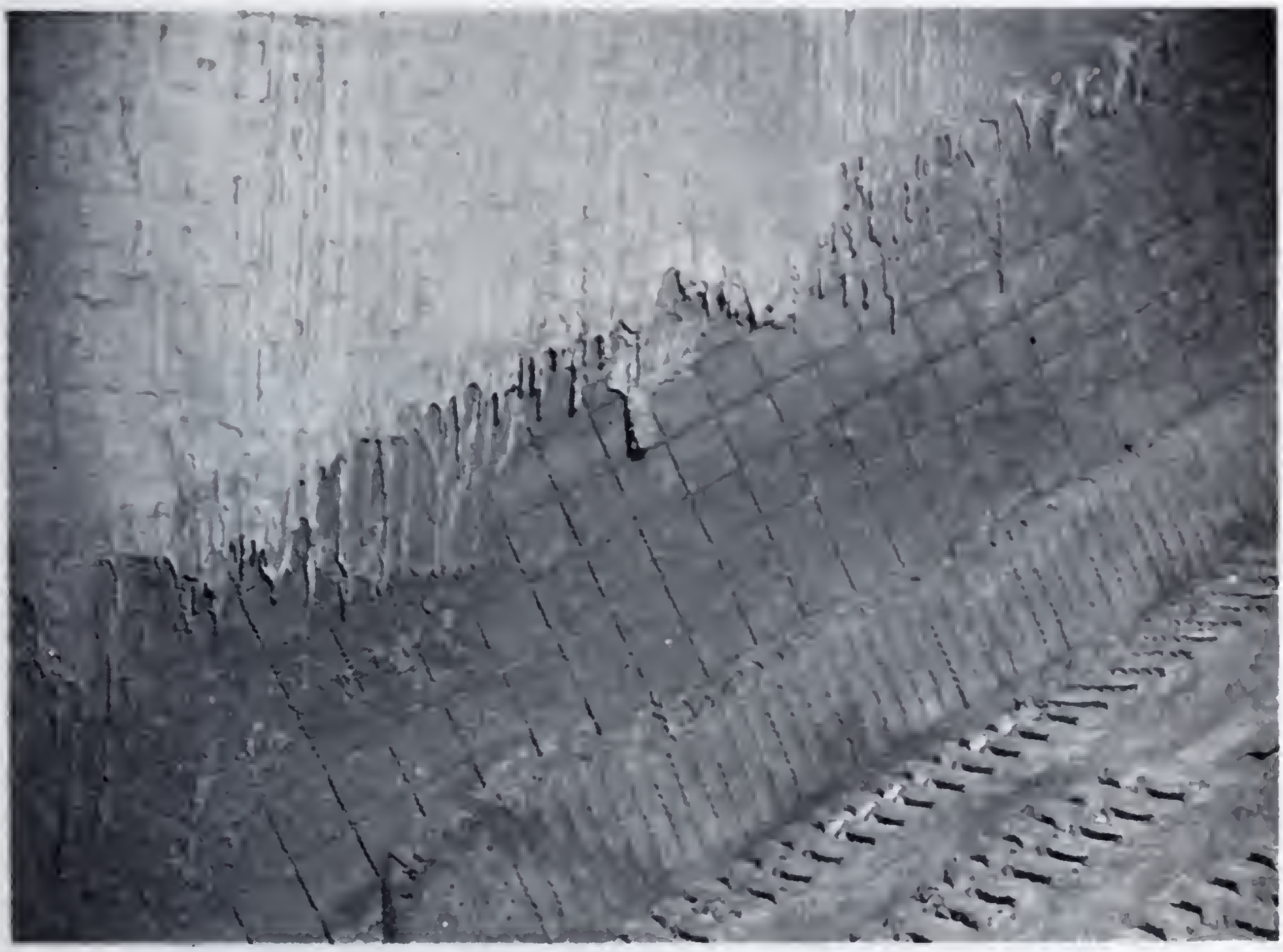


Fig. 3. Interior of Furnace Showing Slag Accumulation above Water-Wall.

Fig. 4. Interior of Furnace after Four Months of Continuous Service.

temperatures and high sulphur and iron contents introduced problems that were not overcome satisfactorily with this type of water-cooled construction. As evidence of this, Fig. 3 shows how the molten slag erodes the face of the refractory wall immediately above the water-cooled wall, and how the molten slag extends down over the block-

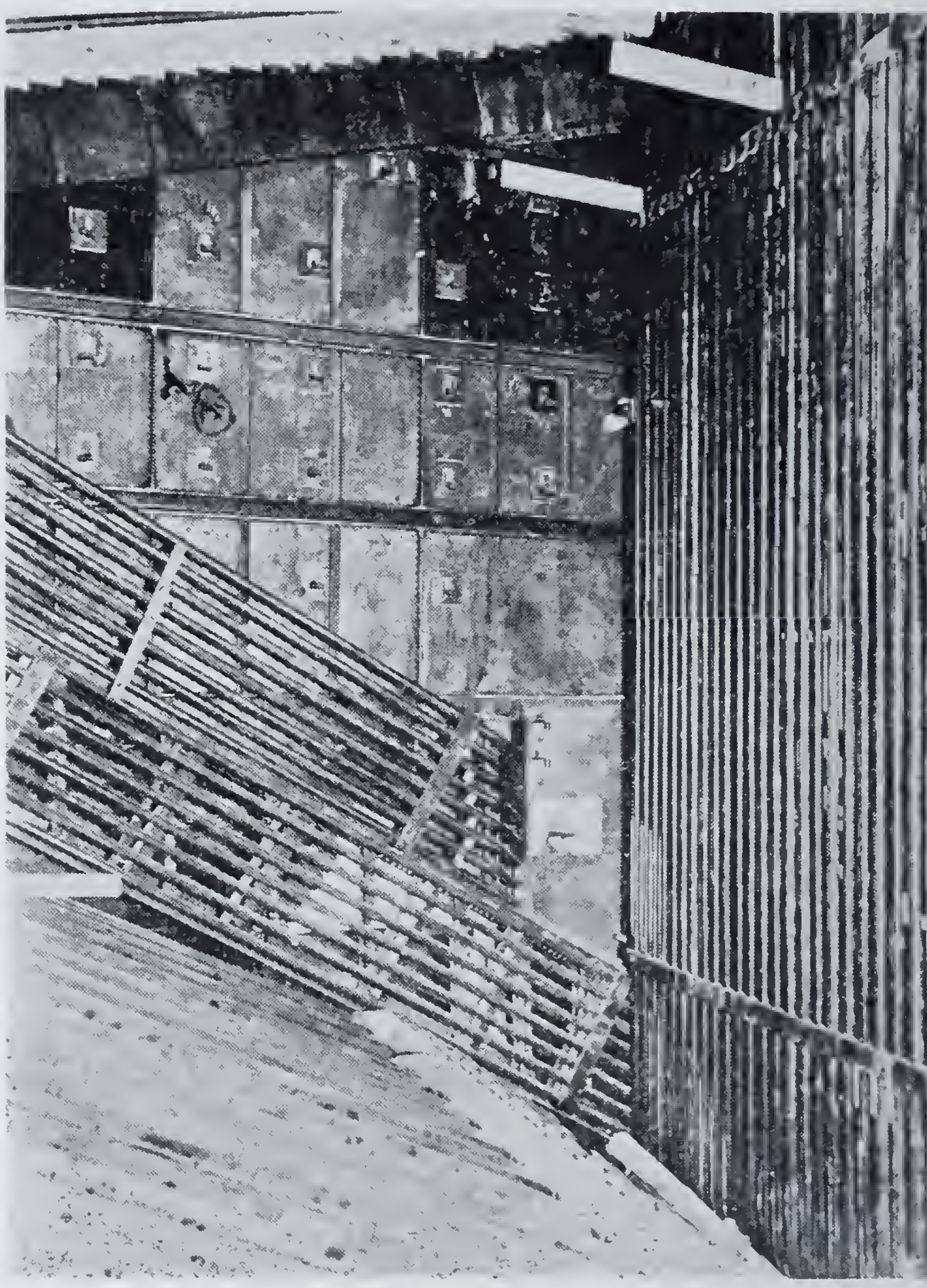


Fig. 5. View During Erection, Showing Arrangement of Bare Tube Section in Side Wall.

covered portion of the wall. In this instance, however, where the furnace was operating under comparatively light duty, the molten slag became chilled and did not extend over the face of the water-cooled wall to any great extent. The illustration indicates this slag formation very clearly.

The furnace illustrated in Fig. 3 was operating with Dominion coal, which has a low fusion temperature and high iron and sulphur content. The composition of this coal is as follows:

Moisture	8.3 per cent.
Volatile matter	33.26 per cent.
Fixed carbon	47.45 per cent.
Ash	10.99 per cent.
Sulphur	2.52 per cent.
B.t.u. per pound	12,129
Fusing temperature of ash	2090 degrees
Ferrous oxid in ash	32 per cent.

Fig. 4 shows a furnace operating under more severe conditions wherein the slag has completely covered the front portion of the water-wall down to the stoker. The coal burned in this case is also of low fusion temperature, running around 2000 degrees F. The illustration indicates the problem encountered when burning such coal at high burning rates—the flow of slag over the face of the water-wall. The molten particles become attached to the brickwork and cover the face of the wall in such quantities that the wall does not chill the slag sufficiently to prevent its adhesion to the protective blocks.

To overcome this difficulty, which is encountered only under severe operating conditions, a construction was developed to prevent the flow of the molten slag over the block-covered portion of the wall by introducing one or more bare tubes located beyond the face of the refractory wall. This construction is illustrated in Fig. 5; also in Fig. 6, which is a cross-section through a wall of this type. The water-wall constructions shown in these illustrations are fully covered by pending patent applications in the United States and foreign countries.

Fig. 5 is an erection view of the installation now being made in Berlin, Germany. It shows clearly the opening provided for the observation door, and the construction required to permit its location where it would be convenient for the operators.

Fig. 6 shows the same furnace after the brickwork was completed and before the unit was placed in operation.

Fig. 6. View of Completely Erected Furnace Shown in Fig. 5.

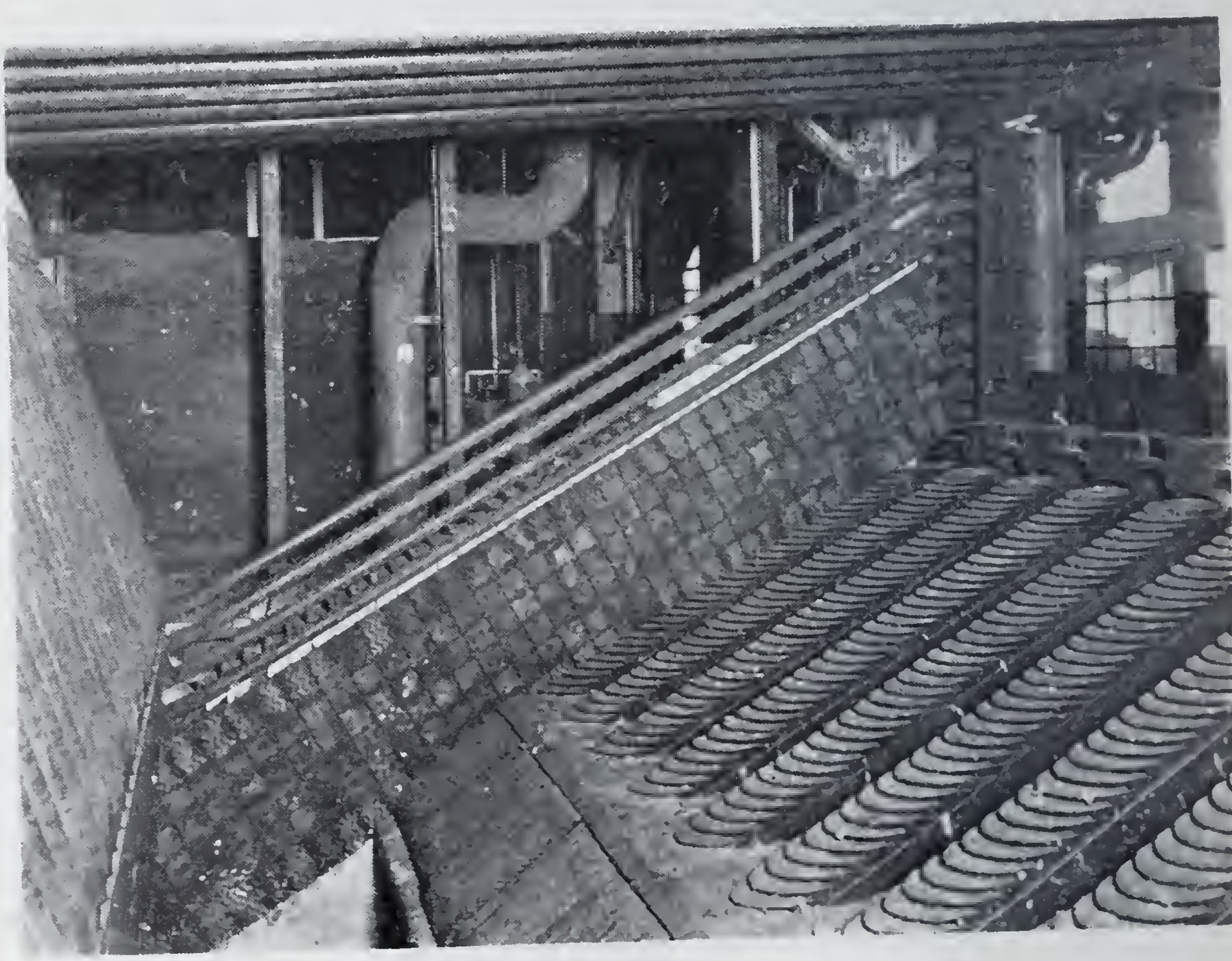


Fig. 7. Block-Covered Side Wall with Bare Tubes Forming Slag Drip.

Fig. 7 shows a similar water-wall and indicates more clearly the block-covered portion and the slag drip construction above it. The operation of this slag drip is shown quite clearly in Fig. 8. The coal burned in this plant is a rather good grade, having a comparatively high fusion temperature, but due to the high CO_2 and consequent

Fig. 8. Operation of Slag Drip Showing Extent of Slag Formation.

high furnace temperature the slag melts and runs down the side wall.

The demand for increased capacity has resulted in the remodeling and revamping of a number of older plants to obtain greater steam output. A large steel plant required additional capacity and it was decided to revamp the old boiler units rather than install complete new units. The original installation consisted of a bent-tube

boiler equipped with a rather antiquated type of underfeed stoker and it was impossible to operate this at high ratings, due to high furnace and stoker maintenance. This installation is shown in Fig. 9.

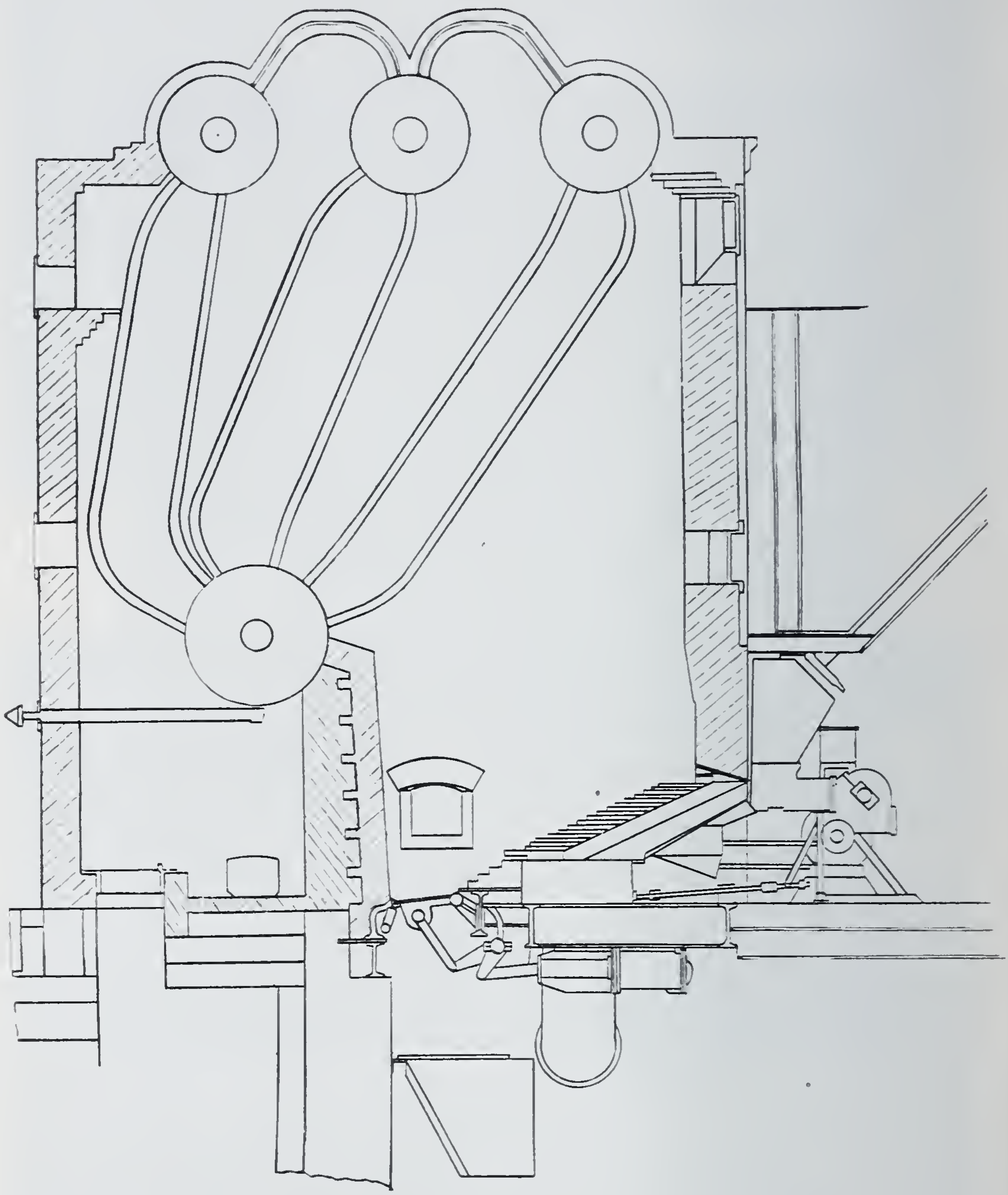


Fig. 9. Original Installation in Large Steel Plant.

In order to provide additional capacity, a larger stoker of the modern type was installed, equipped with side and rear water-cooled walls (Fig. 10). One of the very decided advantages in the use of

water cooling for rear furnace walls is very clearly illustrated in this case. In order to obtain the capacity desired, at moderate fuel-burning rates, it was necessary to install a stoker much larger than the original one. The use of the rear water-walls permitted the extension of the stoker underneath the bottom boiler drum. This

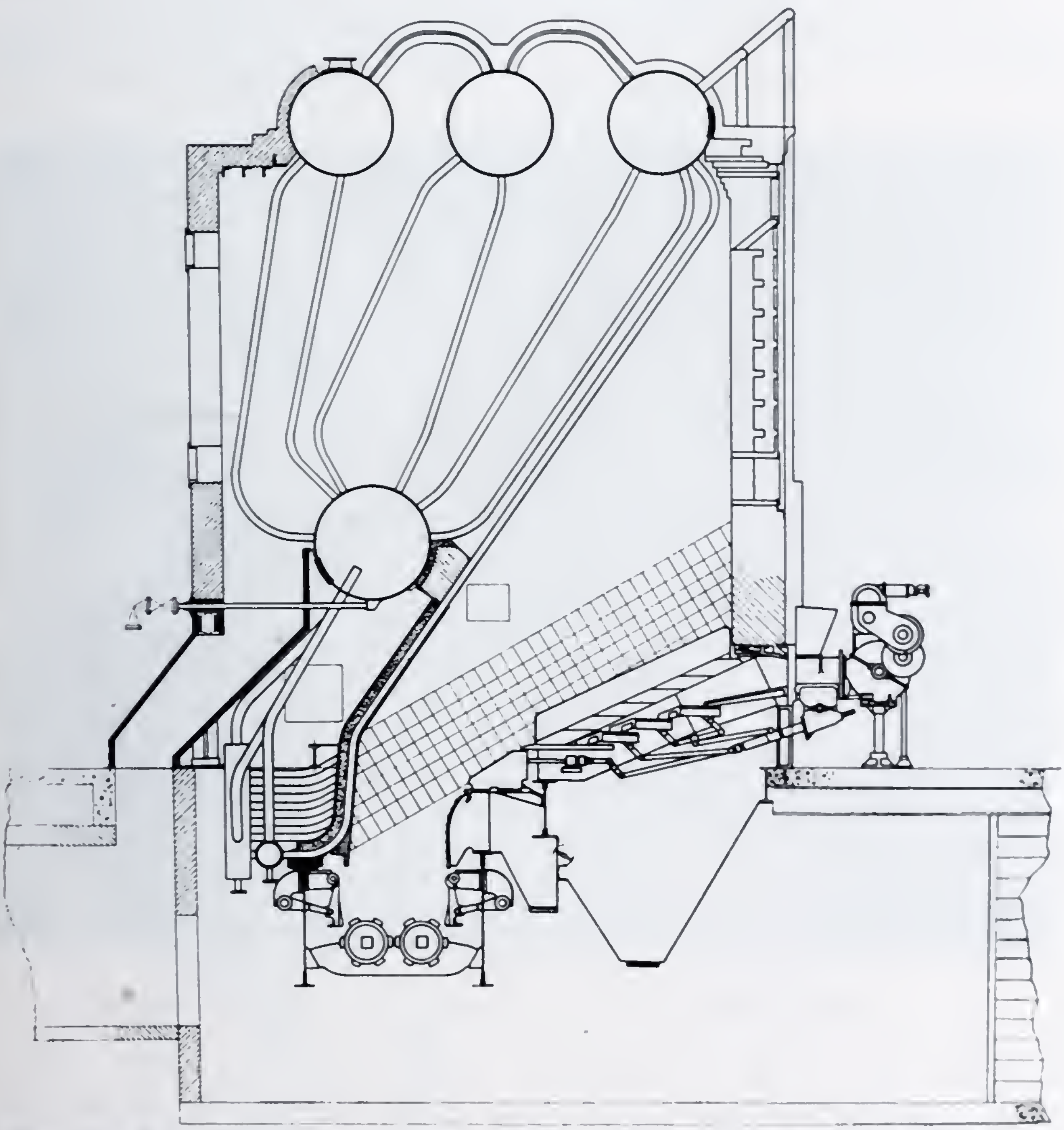


Fig. 10. Remodeled Plant Showing Water-Cooled Side and Rear Walls.

construction, in addition to making it possible to install a longer stoker, also acts as a slag screen for the boiler.

Fig. 11 is an erection view of this installation and the manner in which the rear water-wall extends back beneath the drum and also the detail construction of the side water-wall. The installation of this larger stoker in connection with the water-walls resulted in an

increased steam output of 60,000 pounds of steam per hour. The cost of obtaining this added steam output was $1.30 per pound of steam. The revamped unit has now been in operation for over a year and the operating results show a saving of nearly $16,000 in coal alone over the previous installation.

Another instance of the installation of water cooling to increase capacity is shown in Fig. 12. In this plant, side walls and a rear water-wall were installed without making any changes in the original

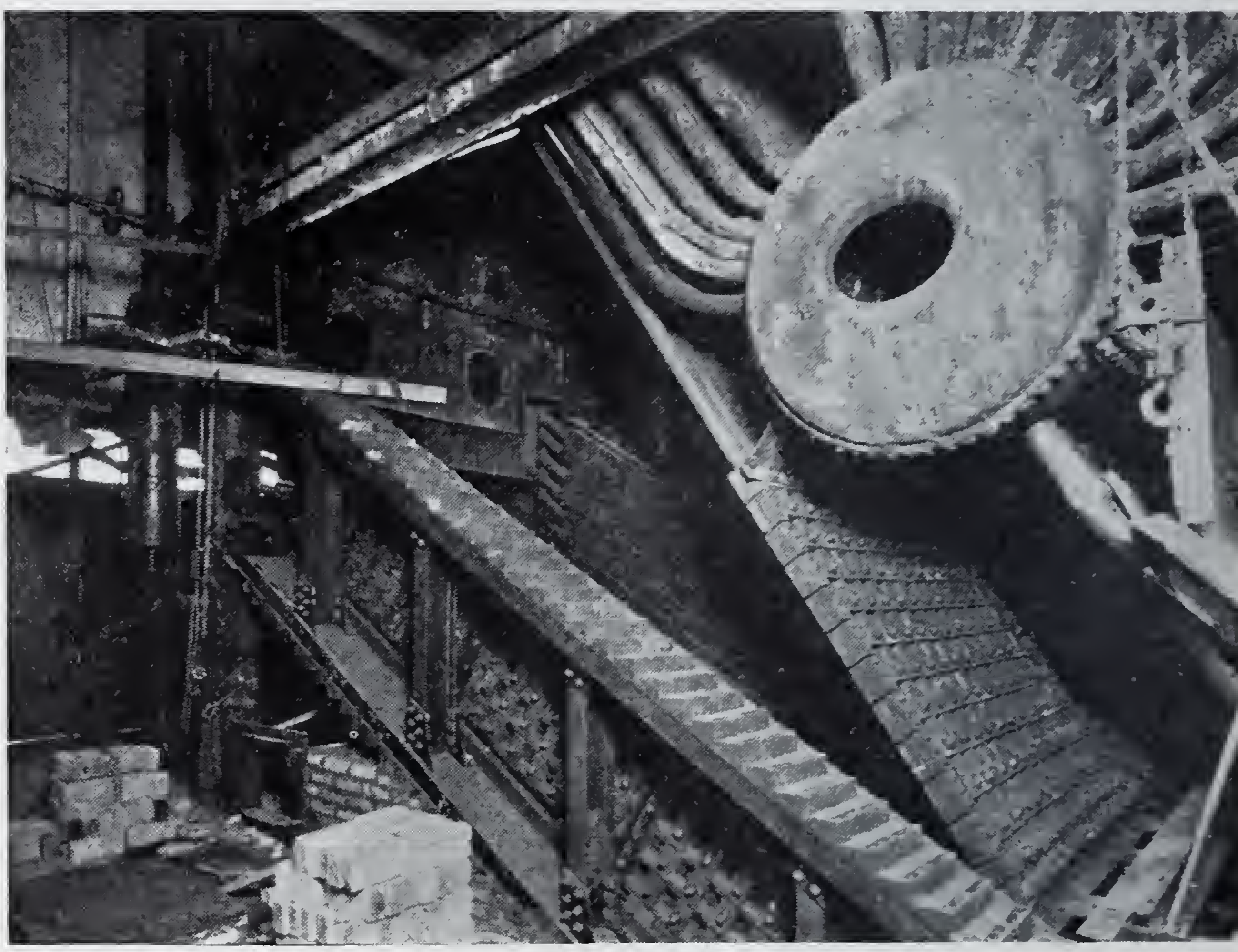


Fig. 11. Erection View of Furnace Shown in Fig. 10.

stoker. The side-wall construction in this case consists of a section of block-covered tubes, above which are placed several bare tubes, forming a slag drip. This furnace is illustrated in Fig. 8.

The installation of water-walls in this plant has resulted in an increased capacity of 50,000 pounds of steam per hour, and the cost here amounted to 82 cents per pound of additional steam capacity. Comparing this cost with the cost previously mentioned, you will notice that it is considerably less. This is due to the fact that in the latter instance there were no changes made in the stoker. The fur-

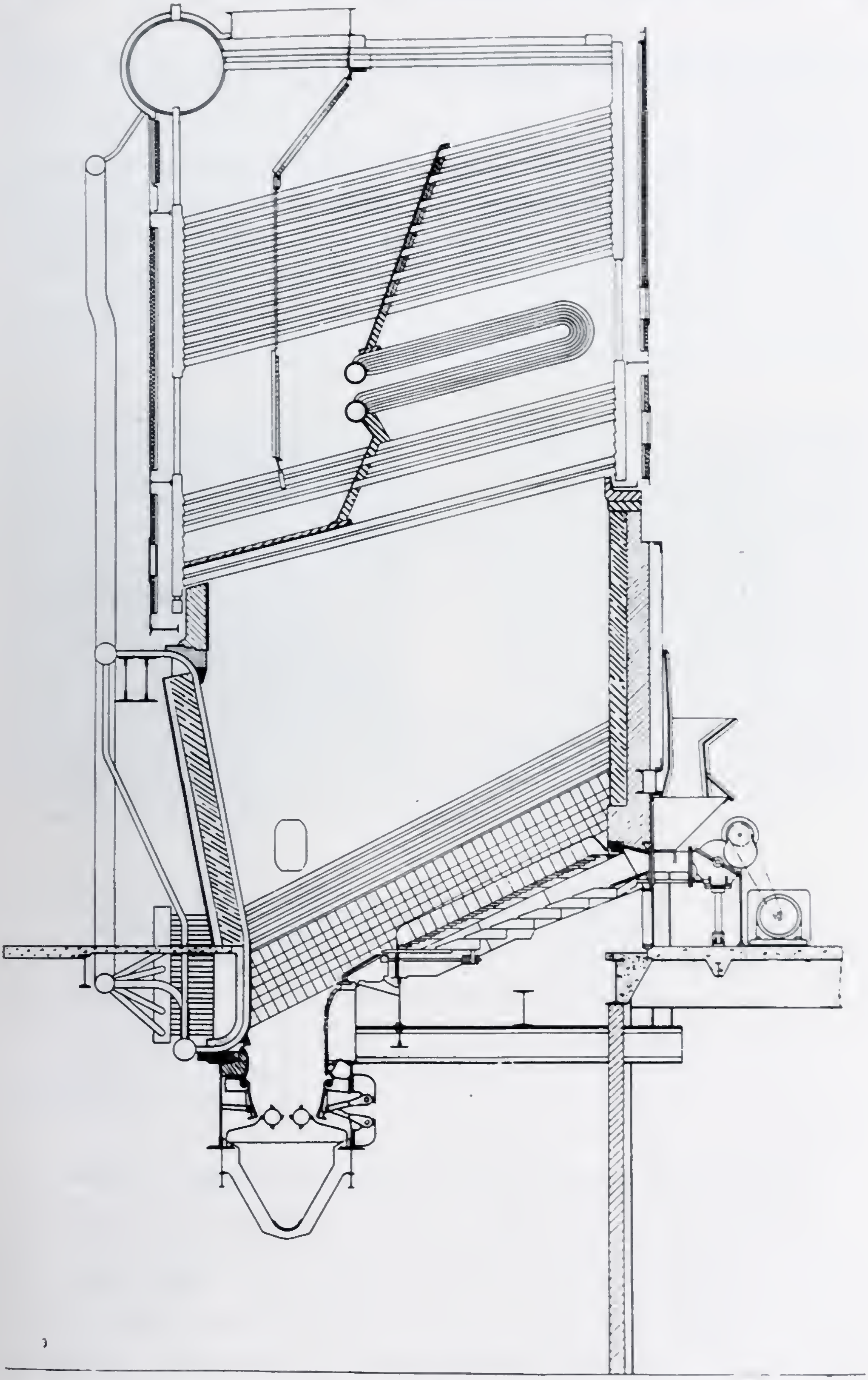


Fig. 12. Stoker Setting Showing Addition of Side and Rear Walls to Original Furnace.

nace was revamped simply by the addition of water cooling, while in the previous case a new stoker was installed along with the water-cooled walls.

A large central station in the East has found it necessary recently to obtain additional capacity from the limited building space available. Fig. 13 shows the original furnace and setting before changes were made, and also the revamped setting where 50 per cent. additional capacity was obtained by installing a larger stoker and additional water-cooled area in the rear wall. In this case the cost

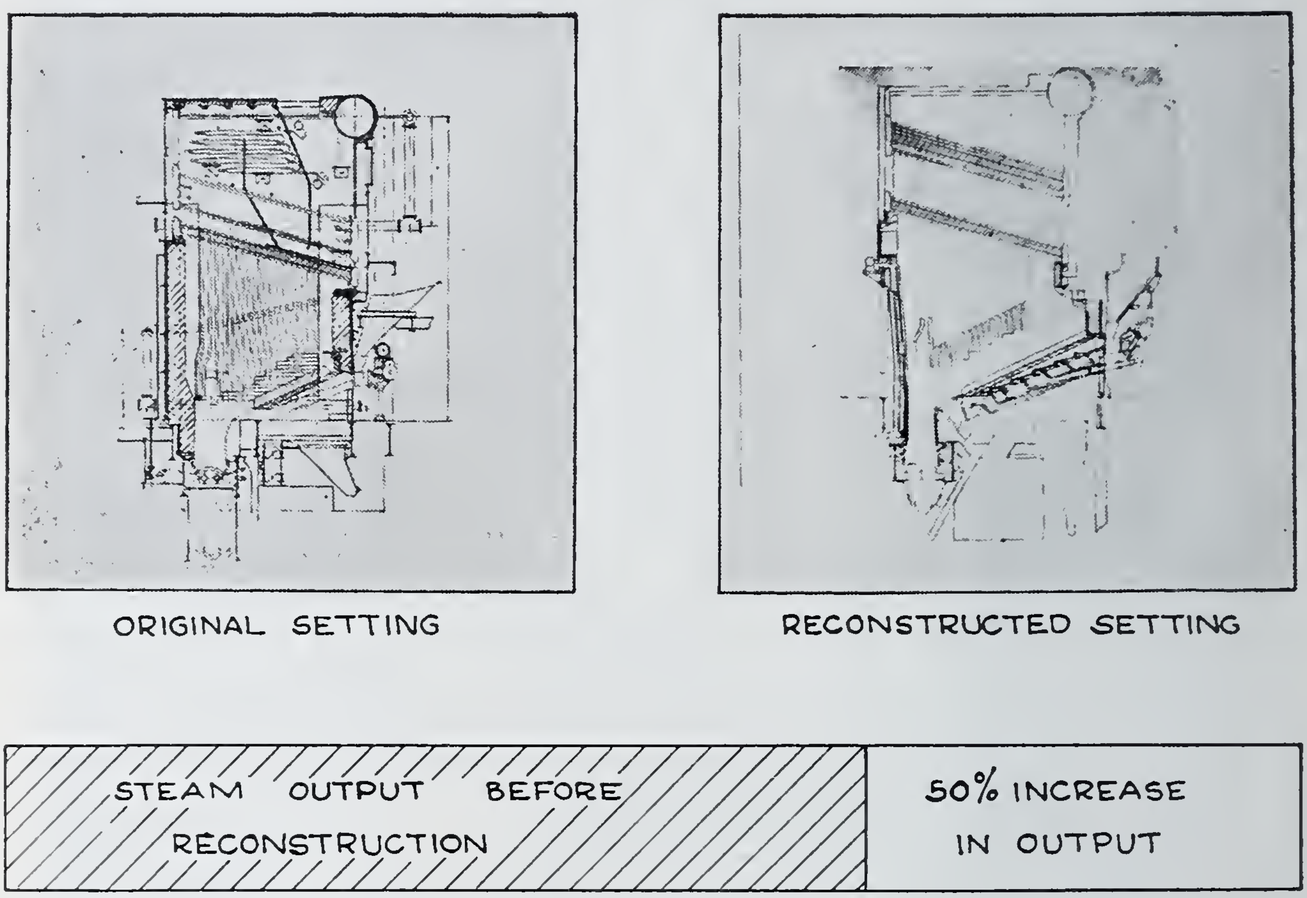


Fig. 13. Remodeling of Central Station for Increased Capacity.

of this additional capacity amounted to $1.15 per pound of steam per hour.

Another large central station in the East increased its steam output in much the same manner as those installations previously described. In this plant a larger stoker of the modern type was installed and also side and rear water-cooled walls. The water cooling in this case is also a combination of block-covered wall with the bare slag drip tubes immediately above it. A view of this installation during erection is shown in Fig. 7. In addition to installing a larger stoker and the water-cooled walls, a row of tubes was added to the

bottom of the main bank of boiler tubes, forming a slag screen as shown in Fig. 14.

Design of power plants in the United States with reference to the application of water-cooled furnaces, both for pulverized fuel and stoker firing, is far more advanced than in Europe. Lately, however, there has been a decided increase in the use of water cooling

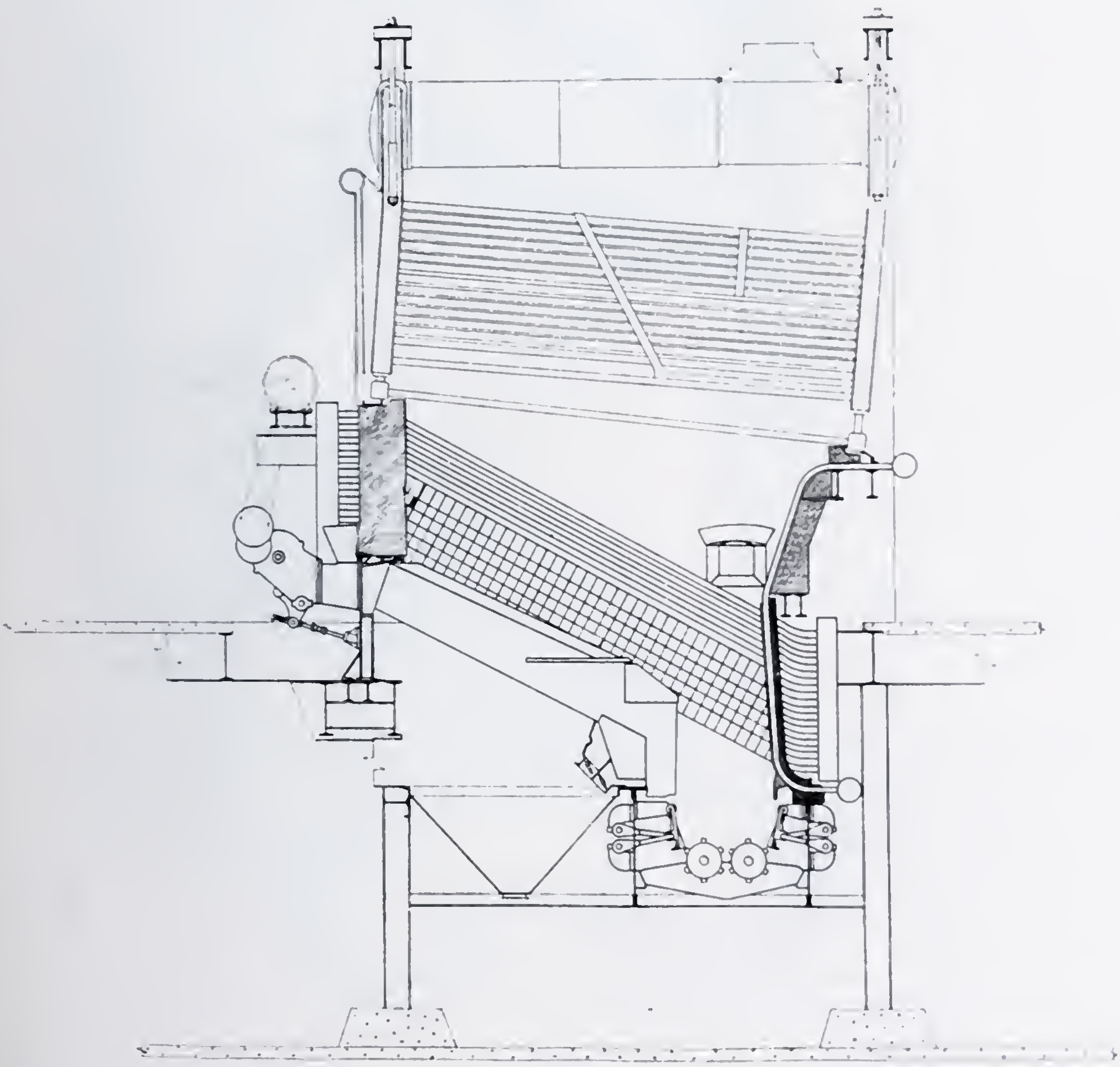


Fig. 14. Reconstructed Furnace of Large Central Station.

abroad. As evidence of this fact it may be said that the newest and largest plants now being projected in Europe are making use of water-walls of American design. These installations include the Gennevilliers station in Paris, the Bewag station in Berlin, and the Deptford East and Deptford West stations of the London Power Company.

The Gennevilliers installation is shown in Fig. 15. This installation is very interesting since it is equipped with a new type of single-pass boiler of French make, called the Rauber boiler, which is

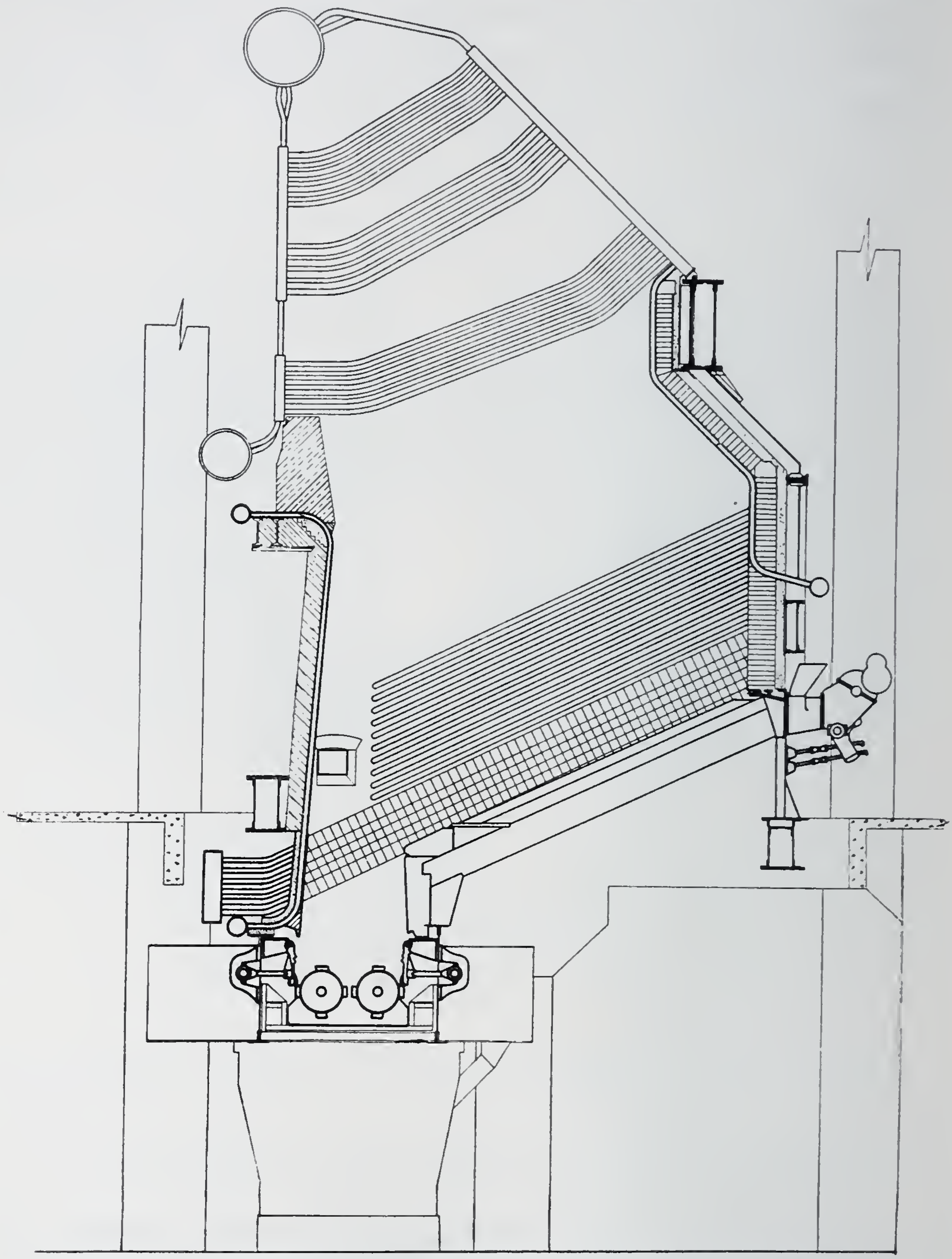


Fig. 15. Installation of Front, Side, and Rear Water-Walls.

especially designed for high evaporative rates. The Gennevilliers installation will be equipped with side and rear water-cooled walls, the side walls consisting of six tubes covered with protective blocks,

above which are placed 10 bare tubes, forming a slag drip similar to the installations previously described.

Another French installation, shown in Fig. 16, is equipped with side and rear water cooling. The boiler is an Alsthom type, having 11,800 square feet of heating surface.

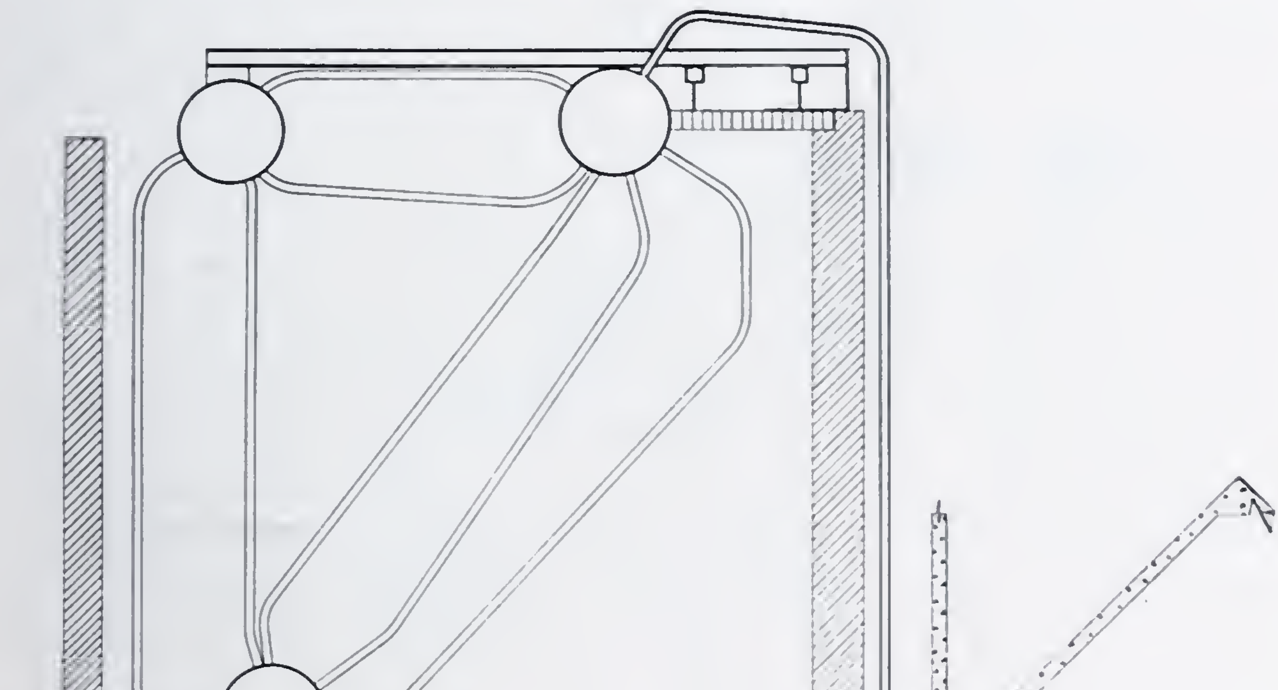
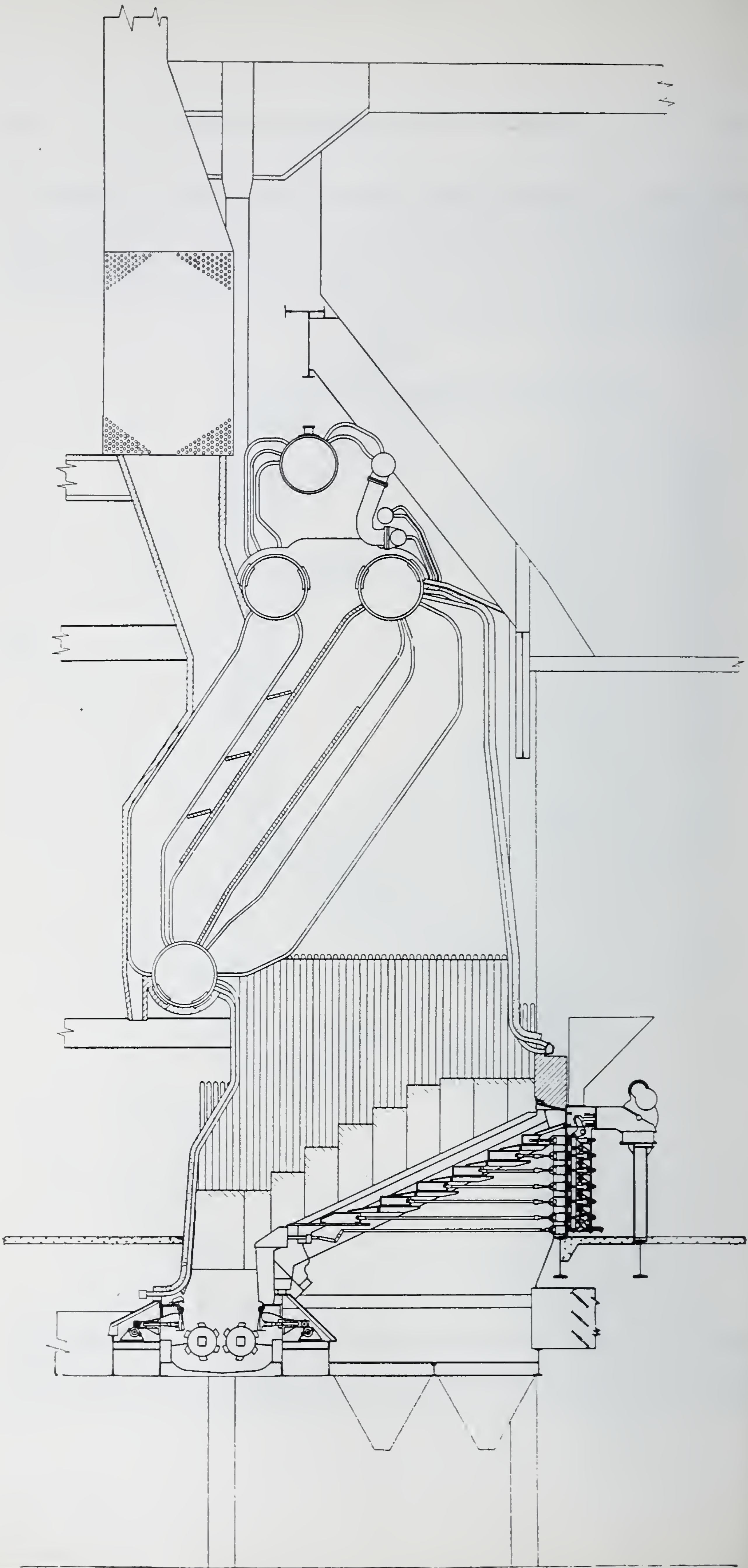


Fig. 16. Side and Rear Water Cooling.

The new units for the Hudson Avenue station which have been widely discussed are illustrated in Fig. 17. Here the station was forced to increase its output and was limited by the space available. The present units have a capacity of 385,000 pounds of steam per



hour and it was found after careful study that 530,000 pounds of steam per hour could be obtained in the same building volume. It is interesting to note the design of this installation and the methods employed to accomplish the desired increase in capacity.

The bottom boiler drum is placed to the rear of the existing building columns and the tubes of the rear water-wall are extended directly into this drum. The stoker was so located that the crusher rolls straddled this same column.

This stoker is 15 retorts wide and 69 tuyeres long. It is the longest single-ended stoker built in this country or abroad. A most interesting feature is that there will be two operating floors (one of which is shown in this illustration) from which the various adjustments to the stoker operating mechanism are made. The other operating platform will extend on a level with the top of the main coal-feed rams of the stoker.

This furnace is equipped with side water-walls of the vertical type and also, in addition to the rear wall, has a front water-cooled wall.

DISCUSSION

W. N. Flanagan, *Chairman:** We have had an excellent paper which ought to lead to considerable discussion. I want to call on J. B. Crane to open the discussion.

J. B. Crane:† Mr. Oberholtzer has given a very clear description of water-walls as applied to stokers, especially underfeed stokers. Water-walls are also used with chain-grate stokers, and with pulverized fuel, natural gas, oil, and blast-furnace gas. The early development of pulverized fuel covered the application of water-walls to the rear wall of the boiler, and this subsequently extended to the side walls and finally to all four walls, so that now for pulverized-coal firing it is customary to inclose all four walls of the furnace with water cooling and to cut down the refractory as much as possible, as slagging tends to build up on refractory surfaces and later extend to the water-wall.

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†District Manager, Combustion Engineering Corporation, Pittsburgh.

With natural gas there is not as much transfer of heat to the water-walls as with pulverized coal, and the temperature is not reduced as much before entering the boiler tubes, but it does reduce furnace maintenance.

It was claimed for a long time that we would never be able to burn blast-furnace gas in completely inclosed water-cooled furnaces, and that it was necessary to have refractory in order to provide ignition temperature. About two years ago we placed in one of the steel plants two installations with water-cooled furnaces for burning of blast-furnace gas. The mixture of gas and air was introduced from the four corners so as to give as much turbulence as possible, and much to everybody's surprise it has proved one of the best installations for burning blast-furnace gas that has ever been put in operation. Later we used the standard plan of introducing blast-furnace gas through burners in the front wall, using refractory material in this wall, and a water-cooled surface on the rear wall and the two side walls, and this also has proved very successful, so that most of the installations that are now going in for blast-furnace gas use water-cooled furnaces.

We are now getting some very good figures on maintenance cost, and find that some of the furnaces have been in four or five years and have had absolutely no repairs. On others the maintenance has amounted to the replacement of one or two tubes in the walls. On refractory furnaces, when operated at high ratings, it is usually necessary to repair the settings at least every year, and in many cases the settings have to be entirely rebuilt at the end of four or five years.

W. N. Flanagan, *Chairman:* W. R. Little might be able to give us some experience with pulverized coal.

W. R. Little:* The author has described the gradual growth, application, and different designs of water-walls as applied to underfeed stoker furnaces. The application of water-cooled furnaces has not been limited to stokers alone, but is also employed for furnaces fired by oil, gas, and pulverized coal. The wide variation in fuels and conditions requires different amounts of cooling and arrangement of furnaces.

*Manager Pittsburgh Office, Fuller-Lehigh Co., Pittsburgh.

To meet these different conditions, our design of water-wall consists of vertical tubes placed six inches from center to center and covered on the furnace side with T-shaped blocks which are clamped between the tubes. These blocks are made of cast-iron with smooth or rough faced surface, or cast-iron blocks with different kinds of refractory facing. By using these different kinds of blocks, the rate of heat transferred per square foot of furnace wall can be controlled with resultant effect on the furnace temperatures. These blocks also afford a protection to the tubes against abrasion and impingement of flame and permit a more uniform flow of heat to the tube surface.

To illustrate the effect of different block arrangement, at the Saxton plant of the Penn Central Light and Power Company, one of the boiler furnaces is constructed with refractory-faced blocks, while the other furnace has smooth cast-iron blocks. During the acceptance tests on these two units, the efficiency of the unit with the refractory blocks was higher throughout the operating range. At 200 per cent. rating, the difference was 2½ per cent.; at 300 per cent. it was one per cent., and at 400 per cent. rating it was three per cent.

Some of the economic advantages obtained by installing water-cooled furnaces are higher efficiency of the unit, lower costs of maintenance of furnace and stoker, less operating labor, and greater availability of service.

R. A. Foresman:* The use of water-cooled furnace walls for stoker work has become rather common practice in one form or another on large and moderately large installations. As far as stoker operation is concerned, water-walls have unquestionably proved their ability to prevent clinker adhering to them. This has made it possible to maintain the uniformity of the fuel bed on the stoker along the side walls, and has eliminated the difficulty caused by the clinker on the rear wall obstructing the disposal of the ash as it was discharged from the furnace. In these respects it has contributed to improving the efficiency and increasing the capacity for a period considerably in excess of what was previously possible. The advantages of the water-wall are more pronounced as the size of the stoker is increased, this being particularly true as the length of the stoker is increased. While the effect of the water-cooled side wall is not so

*Chief Engineer, Stoker Department, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

easily determined as that of the rear wall, in the average case it probably has more effect on the improvement in efficiency than does the water-cooled bridge wall.

If performance such as is common to-day with a water-cooled furnace were attempted with a furnace with refractory walls, the side-wall clinkers from most coals would break up the uniformity of the fuel bed over the first two or three retorts immediately adjacent to each side wall. This condition would lower the efficiency and, if continued for any considerable length of time, would seriously affect the capacity.

As far as we know, no one has been able to establish a definite measure of the value of the water-cooled walls of a stoker-fired furnace. It can be expressed only in higher efficiencies, higher and more dependable capacity, and reduced labor of operation.

The water-cooled front wall has not come into general use and no particular advantage in stoker performance can be attributed to it. It is possible for it to have a detrimental effect upon the combustion taking place immediately adjacent to it. Consequently, it has been our recommendation to use a section of refractory wall of not less than three feet immediately above the stoker throat.

We have little information regarding the manner in which water-cooled furnace walls affect combustion throughout the furnace. Our opinion is that the temperature is considerably reduced immediately adjacent to the water-cooled surfaces, but as to how extensive the area is that is affected, or to what extent the temperatures are reduced, we are not in a position to state with any degree of accuracy. We can say that, where we had the opportunity of making comparisons, the difference between the straight refractory wall, the refractory-faced water-cooled wall, and the bare water-cooled wall, did not prove to be nearly so important as we had anticipated.

As far as we can determine, no reduction of stoker maintenance can be attributed directly to the use of the water-wall. By this we mean that the furnace temperature and combustion in general are not in themselves sufficiently altered to bring about a reduction.

Most of the burning of stoker parts is caused by large clinkers which are not moved by the slow normal action of the rams. If a

large clinker is suddenly dislodged, manually or mechanically, it carries with it much of the combustible and ash which serve as insulation to the stoker, and allows hot masses to cave in directly upon the bare iron.

Water-walls do prevent the formation and adhesion of large clinkers adjacent to the walls, and thus reduce maintenance. As a heat-absorbing element, their value will be high in relation to the remainder of the heat-absorbing unit. Sufficient time has not elapsed to determine the real maintenance of a water-cooled furnace wall. Although we are not engaged in the manufacture of water-walls, we recommend their use in practically all cases, leaving it to the user to select the make and type he prefers. Under these circumstances, we are interested in the wall only to the extent that it influences the stoker performance, and not in its overall economic worth.

If these walls will stand up for substantially as long a period as the remainder of the heat-absorbing unit, they will, undoubtedly, have a high economic value. If the reverse is true and substantial replacements are required in relatively short periods of time, their economic value will be reduced accordingly.

W. N. Flanagan, *Chairman:* We have heard so far from those interested in designing and installing water-walls, I think we should now hear from one of our operating friends. T. E. Purcell, of the Duquesne Light Company, is always interesting.

T. E. Purcell:* This paper has set forth in a very able manner the case of the water-cooled furnace. There are still a few engineers somewhat skeptical of the merits of water cooling. This paper should be carefully reviewed by such persons. I assure them that until they give this type of construction a fair opportunity to demonstrate its usefulness and economic saving, they have not fulfilled their duty to their employers or clients.

The fundamental reason for applying water cooling to furnaces has not been for the purpose of increasing the steam-generating surface, but rather to reduce furnace maintenance, to reduce clinkering and slagging, and to permit operating with decreased amounts of excess air.

*General Superintendent of Power-Stations, Duquesne Light Co., Pittsburgh.

The experience of the Duquesne Light Company with the water cooling of furnaces began in 1915 with the use of a water-cooled tube connected into the boiler circulation system and placed at the rear of a furnace fired by a chain-grate stoker.

Our company has passed through successive stages of development until a maximum of water-cooled surface was employed in the last installation of a pulverized-fuel boiler at the Colfax power-station, where the furnace is bounded on four sides and the bottom with water-cooled linings, the top boundary of the furnace being cooled by the boiler tubes. Even this ultimate use of water cooling of all furnace boundaries, combined with the latest practice in operation of pulverized-fuel burners, proved to be insufficient to depress the temperature of ash (fusing at about 2300 degrees F.) sufficiently before entering the boiler to prevent slagging of the boiler tubes when operating at high capacity and at a heat release of about 30,000 B.t.u. per hour per cubic foot. The slag screening of the boiler has in some measure relieved tube slagging, but the extent of screening we have adopted has not eliminated this as a major factor, limiting continuous operation with low excess air at high capacity.

The water cooling of stoker-fired boiler furnaces in some respects constitutes a different problem, requiring a different distribution of water-cooled surfaces from what is common with pulverized-fuel furnaces. The linings in the upper zones of the stoker furnaces are not subject to the punishment experienced in pulverized-fuel furnaces. The radiating surface of the stoker fuel bed is also smaller in proportion to the total furnace boundary, and allows the use of less capacity for absorption of radiant heat if the furnace temperature is not to be depressed to a point interfering with combustion. These influences, along with the cost differential between refractory walls and water-walls, have led to a more reluctant application of water cooling to those zones of the furnace situated somewhat beyond the points subject to the most severe service.

When, in 1923, pioneering in the water cooling of the side-wall areas of pulverized-fuel furnaces seemed desirable, the Allegheny County Steam Heating Company, Pittsburgh, besides installing the largest boiler in the world at that time, installed water cooling in the side walls of the furnace. Just how and where these water-wall

tubes were to be placed was a subject of much debate. At one side wall the tubes were placed inside of the furnace parallel to, but six inches beyond, the face of the refractory wall, thereby cooling the refractory. Like the water screen, it was supposed to cool the floating ash particles before they impinged on the refractory surface. The other side wall was cooled by recessing the tubes in the wall with the furnace side of the tube tangent to the plane of the refractory wall surface. It developed that placing the tubes in the furnace several inches beyond the refractory face of the wall was not a desirable design; so the original side wall and some back wall installations with the extended tube were rebuilt, the tubes being placed against the faces of the refractory walls. The recessed-tube construction gave good results. This type of design is used in some sections of the furnaces at the James H. Reed station, recently completed.

In order to obtain greater cooling, the plain-tube type of wall in some of the later installations was replaced with the fin-tube type of construction. Our experience with the standard fin tube has been entirely satisfactory.

When the complete water cooling of pulverized-fuel furnaces was considered in connection with the latest addition to the Colfax station, in one of the furnaces, the water-cooled surface, on the front, rear, and side walls (with the exception of a small section near the bottom of the walls) was faced with refractory in order to insure, as we thought, good combustion conditions. The furnace temperature maintained during operation at high capacity and with low excess air resulted in severe slagging of the walls and over the boiler tubes of the first pass. As a result, some of the refractory areas were replaced with metal-faced blocks and the refractory removed from others. The only refractory water-cooled area left in the furnace now is in the front wall above the burners. Combustion is not affected in the operating range of this boiler by the extensive use of exposed metal water-cooled areas.

Many of the water-walls for large boiler units make use of recirculation. In these installations, make-up and steam vent lines connect the water-wall to the boiler proper, the wall itself being provided with recirculating tubes. All our recent installations are built on this principle.

W. N. FLANAGAN, *Chairman:* We are certainly indebted to Mr. Purcell for the talk he has given not only on design but also on operating troubles. We have with us another member who is very well qualified on this subject, Dudley Pendleton.

D. D. PENDLETON:* The subject of this paper has been of particular interest to the writer. The use of water-walls has undoubtedly materially lessened the time during which a boiler is out of service, and reduced the cost of maintenance and repairs.

The firm with which I am connected is a pioneer in the field of water-wall designs, and installed the water-backs at Grand Rapids, referred to in the paper. It was realized at that time that a water-back could be regarded as only a partial remedy for the troubles encountered in operating furnaces, particularly at high ratings and accordingly, as early as 1923, water-walls in conjunction with radiant-heat superheaters were designed so as to cool completely the two sides and rear wall of a stoker-fired furnace. This furnace went into service in 1924 and is still in successful operation. Due to the successful operation of this furnace with walls cooled by water and steam, the installation of water-cooled and steam-cooled walls became quite common, and, as is now well known, is almost standard equipment.

Mr. Oberholtzer, in his paper, has covered the development of the water-wall for the protection of the bridge wall and side walls for an underfeed stoker-fired boiler. As pointed out by him, the addition of this equipment for stoker-fired boilers not only decreased the operating cost and the shut-downs for repairs, but also increased the capacity of the unit.

Completely water-cooled and steam-cooled furnaces such as are now used for burning powdered coal, oil, and gas, as well as for underfeed and chain-grate stokers, add materially to the quantity of steam that can be generated from a given boiler unit. In operating units of this type at high ratings, however, the exit gas temperatures are usually exceedingly high and in order to make the unit efficient, and obtain the benefits of the high heat liberation per cubic foot of furnace volume, it is usually necessary to install equipment for waste-heat recovery, such as economizers and air preheaters, in

*Foster Wheeler Corporation, Pittsburgh.

connection with the other equipment, making a complete, self-contained, efficient steam generator.

I should like to call attention to Fig. 18, showing a cross-section of a steam generator of 1872 horse-power, which is installed

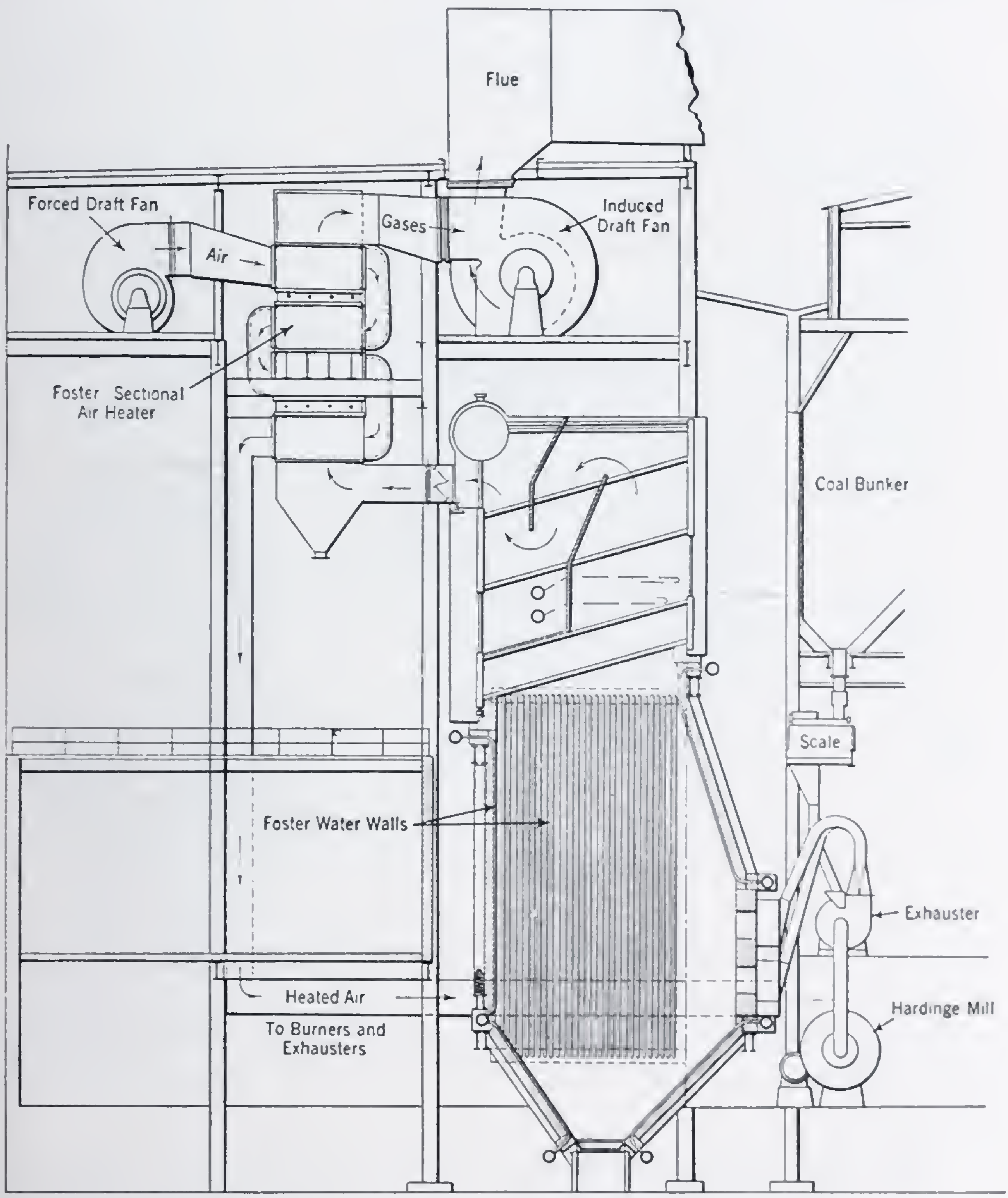

Fig. 18. Water-Cooled Furnace for Powdered Coal.

at Cabin Creek, W. Va. This shows a water-cooled furnace fired by powdered-coal unit system, with an air preheater for waste-heat recovery.

Fig. 19 shows a lay-out for a 2447-horse-power steam generating unit for this same company. This shows a completely water-cooled

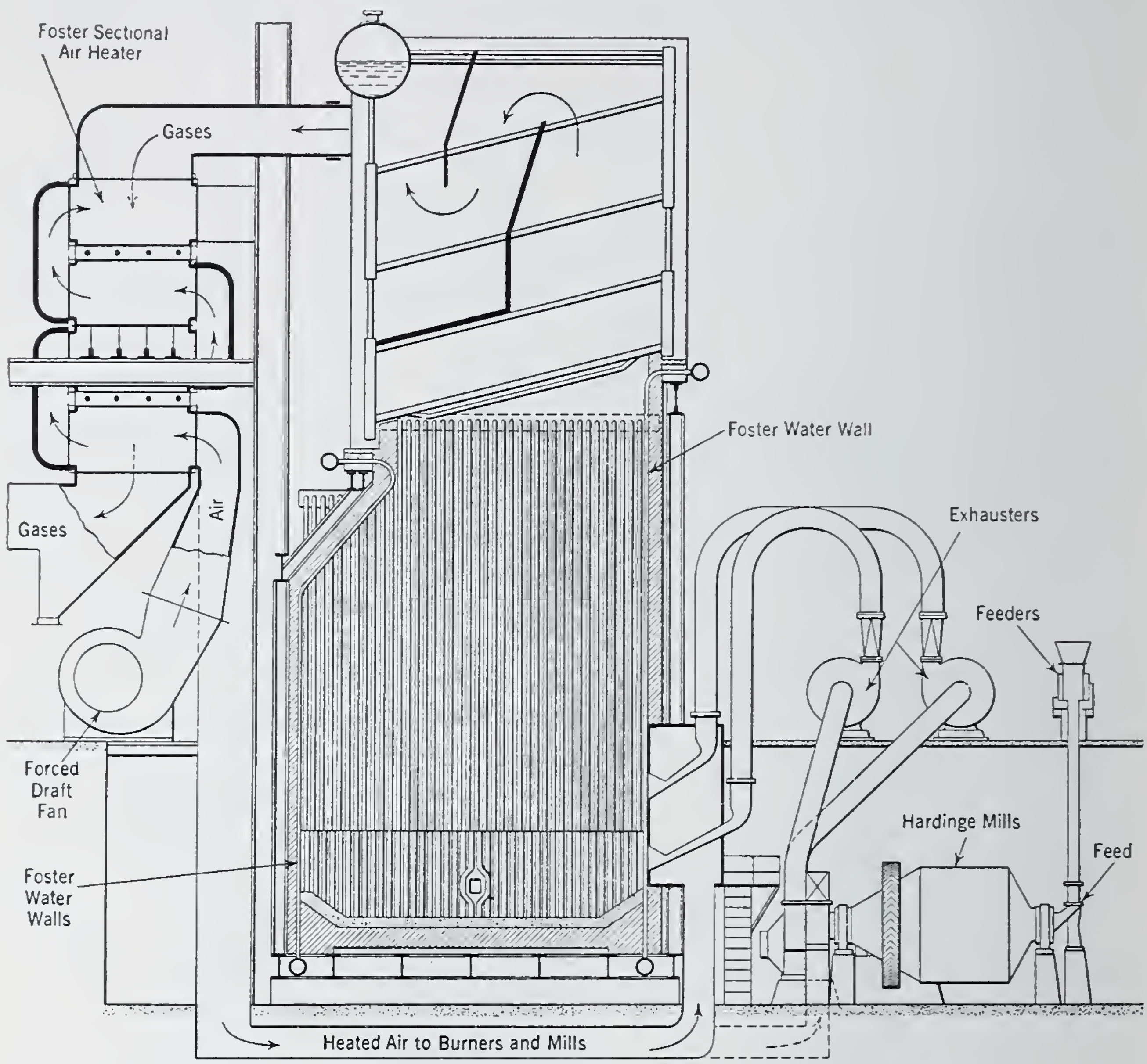

Fig. 19. Water-Cooled Furnace for Powdered Coal.

furnace arranged for powdered-coal firing with unit system, with slag furnace bottom, the ash being drawn off from time to time in a molten state.

These two figures show typical installations.

Fig. 20 shows an installation of a steam-generating unit which operates at 1450 pounds pressure at a steam temperature of 810 degrees. This unit is designed for gas or oil firing and is water cooled with the exception of the front wall. This is practically a two-pass boiler, delivering the gases to the economizer at high temperatures, the gases passing through the economizer, thence to

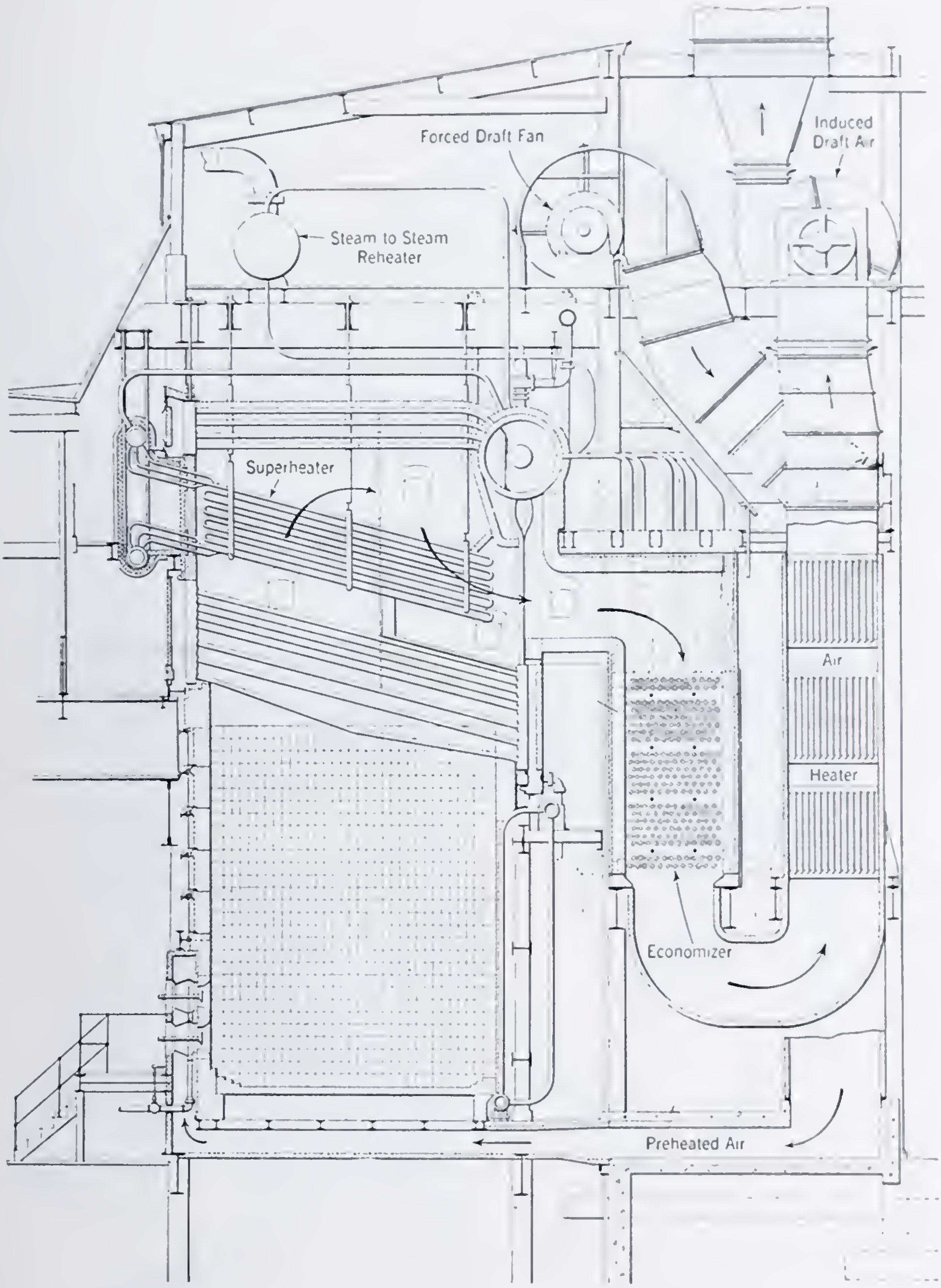

Fig. 20. Steam Generating Plant Operating at 1450 Pounds Pressure.

an air heater. An interesting feature of this unit is steam to steam reheater and high-pressure economizer connections.

Fig. 21 shows a very interesting water-cooled furnace used with a chain-grate stoker. This also shows a two-pass boiler, with the economizer and air preheater as heat-recovery apparatus. This steam

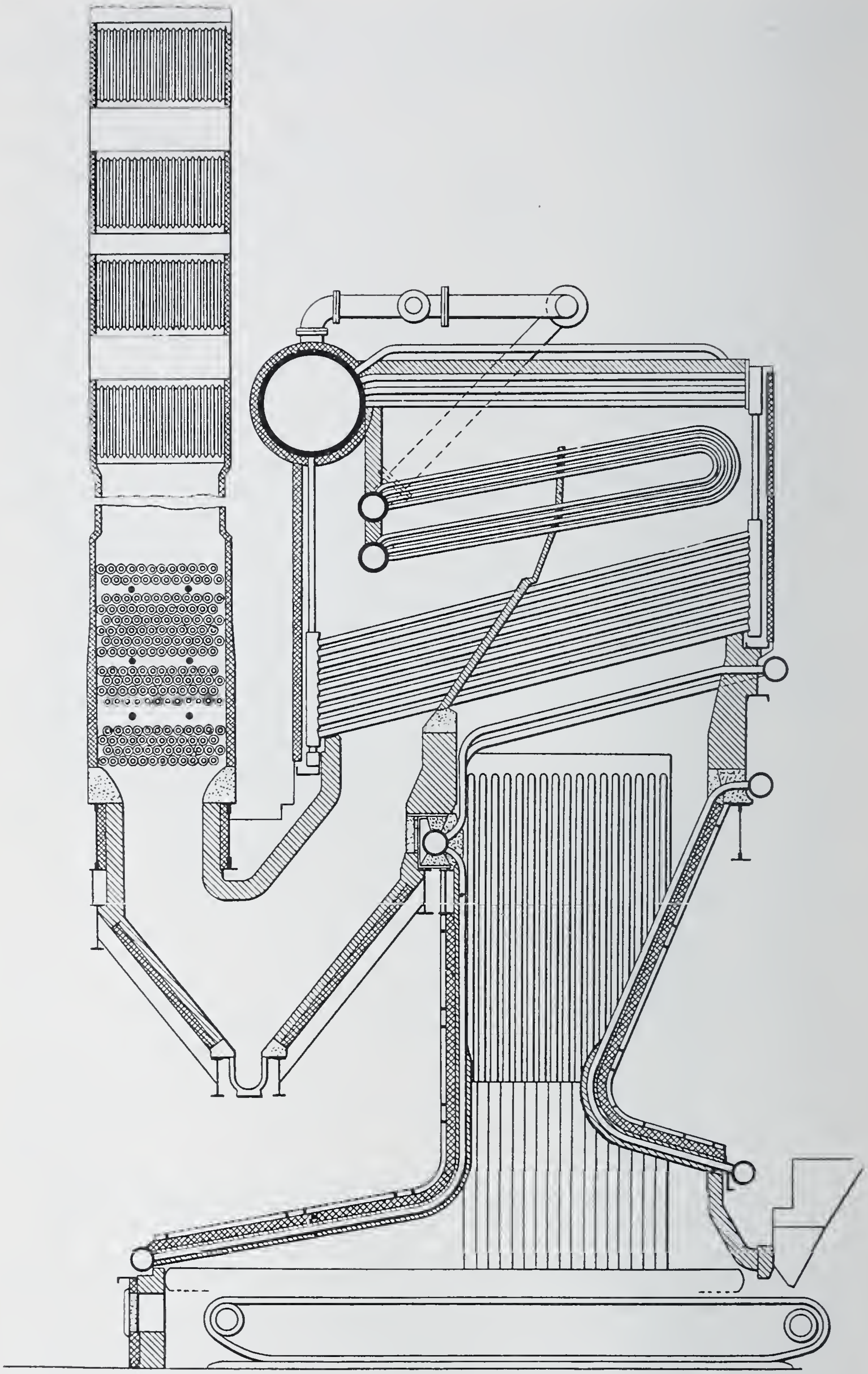

Fig. 21. Steam Generator of Kansas City Power and Light Company.

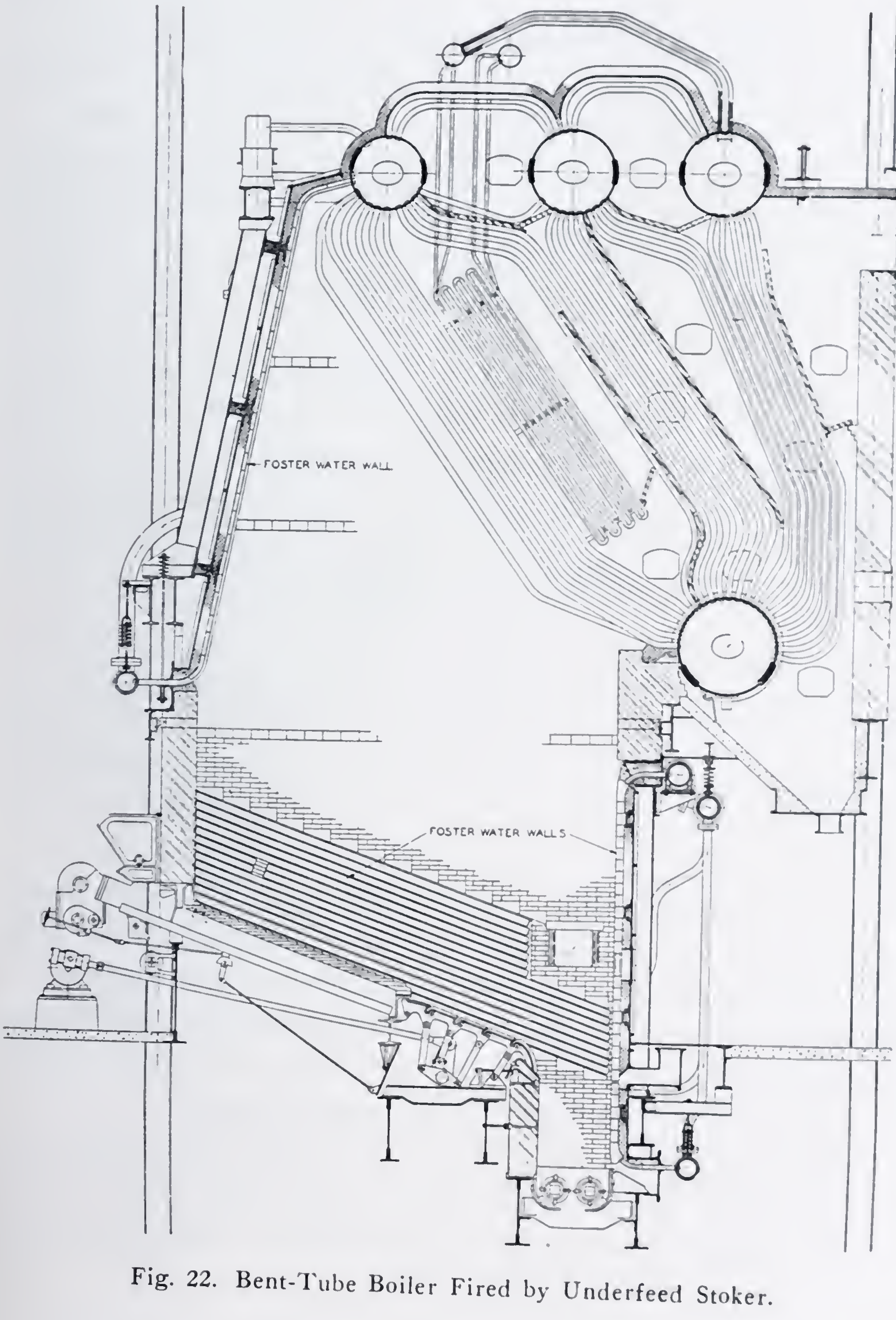

Fig. 22. Bent-Tube Boiler Fired by Underfeed Stoker.

generator consists of a Walsh & Weidner boiler fired by a chain-grate stoker in Foster Wheeler water-cooled furnace and equipped with Foster Wheeler convection superheater, economizer, and sectional plate-type air preheater. Flue-gases enter two vertical groups of air-heater sections from the bottom. The preheated air leaves the lower sections through a common duct.

Fig. 22 shows a bent-tube boiler fired by an underfeed stoker, and with armored water-back and side walls, and a water-wall over the stoker in the front wall, practically eliminating the usual front-wall construction. This makes a very efficient unit at high ratings.

W. N. Flanagan, *Chairman:* In general, when you consider that the exposed surfaces of the water-walls are getting radiated heat from the furnace as well as some heat transfer by convection, and consider the length of tubes in series as compared with an ordinary boiler, it is of interest to know how they would work out on treated water. Circulation should be very good and steam-liberating surface relatively large to avoid burning and priming.

The water-walls are in a very prominent position to absorb heat and should be very effective as part of the boiler-heating surface. What is the relative cost of the various types of water-wall surfaces as compared with the same amount of surface in the boiler proper?

P. N. Oberholtzer: Mr. Little mentioned the tests at Saxton where one furnace is equipped with refractory-faced blocks while the other furnace has bare blocks, and higher efficiency was obtained with the refractory-faced blocks. It is doubtful whether the increased efficiency can be attributed directly to the use of refractory-faced blocks since there were so many other variables involved.

Bare blocks permit the operation of furnaces with higher CO_2 and at higher temperatures than refractory-faced blocks. Consequently, in stoker-fired furnaces, higher efficiencies should be obtained with the walls covered with bare blocks.

With regard to the use of these two types of block construction it might be noted that, in a number of cases, especially where high

preheat was used, it was found necessary to replace the refractory-faced blocks with bare blocks.

Where high furnace temperatures must be maintained, a section covered with cast-iron block, adjacent to the stoker fuel bed, with a relatively cheap refractory construction above to maintain the furnace temperature, is much more economical than to cover the furnace completely with a refractory-faced block.

Mr. Foresman mentioned the possibility of water-cooled front walls proving detrimental to combustion. We do not know of any installation where trouble was experienced from the use of a water-cooled front wall extending down to the stoker, although this construction has been used in a number of plants.

Mr. Purcell stated that water cooling in a stoker-fired furnace and water cooling in a pulverized-fuel furnace constitute different problems, and the extent of the water cooling with stokers is limited due to the small radiating surface of the fuel bed of the stoker.

Stoker-fired furnaces require less water cooling than powdered-fuel furnaces because the furnace walls receive most of their punishment adjacent to the fuel bed. Accordingly, the protection of the walls adjacent to the stoker is of prime importance, and the use of water cooling beyond these sections of the walls is not essential. However, a number of installations have been made, using completely water-cooled furnaces with stoker firing, without any harmful effect on combustion.

With regard to the question of the amount of make-up water and the kind of feed-water to be used with water-cooled walls it may be said that since the water-walls are connected to the boiler and the circulation through the water-walls forms a part of the boiler circulatory system, no trouble will be encountered if the water is suitable for use in the boiler alone. In other words, the amount of make-up and nature of the feed-water are not affected by the use of water-cooled walls.

As to the cost of water cooling, I refer you to the paper entitled "Economics and Design of Water-Cooled Furnaces," by J. S. Ben-

nett and P. N. Oberholtzer, in *Transactions of the American Society of Mechanical Engineers,* Jan.-Apr. 1930 (FSP-52-4). This paper compares the costs of water cooling for a number of different installations.

The water cooling in the side and rear walls adjacent to the stoker fuel bed should be protected in some manner, to prevent flame impingement and erosion due to the moving fuel bed. Bare tubes may be used above this block-covered section in cases where severe operating conditions are expected.

CONTROL OF MATERIALS FOR THE CONSTRUCTION OF HIGHWAYS AND BRIDGES*

By P. J. Freeman†

You are familiar with the conditions which brought about the establishment of the Department of Public Works of Allegheny County in 1924. On account of the long-delayed raising of the local bridges there had developed an enormous amount of bridge construction necessary to provide adequately for the growth of the community. It was realized that there would be a large amount of material to inspect and test, and in view of this fact the speaker was asked by Norman F. Brown, the newly appointed Director of Public Works, to join his new organization and establish a Bureau of Tests and Specifications.

Your attention is called to the name of this Bureau, which is different from that held by kindred bureaus in various municipalities. If it were to be renamed the title should be "Bureau of Specifications and Tests," because the proper function of such a bureau starts with the development of suitable specifications which can be enforced because they cover the available materials which are suitable for construction purposes.

My previous experience with the Testing Laboratory for the state of Kansas and the Pittsburgh Testing Laboratory had taught me the necessity of having adequate specifications for all materials to be used, and that such specifications should conform to the local available sources of supply whenever possible without lowering the quality of such materials. It had been my experience that frequently specifications drawn by engineers and architects would exclude very satisfactory materials through slight technicalities, and an endeavor was made at the very beginning to develop specifications in conformance with the Pennsylvania State Highway Department, the City of Pittsburgh, and the American Society for Testing Materials so that the producers of such materials would have a large demand from other sources and thereby make the inspection of materials easier for all of the purchasers.

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†Chief Engineer, Bureau of Tests and Specifications, Department of Public Works of Allegheny County, Pittsburgh.

Since the entire Department of Public Works was new there were few old prejudices to overcome and no antiquated equipment to be used. The new Department of Public Works consists of four principal bureaus—Bridges, Roads, Architecture, and Tests and Specifications. Each of these bureaus works with the Bureau of Tests and Specifications in the formulation of specifications for materials and construction. In order to induce the County to use a new material it is necessary for the producer to satisfy the engineers of the bureau having in charge that particular kind of construction and the Bureau of Tests and Specifications. Investigations as to new materials or methods of using them are made by the Testing Laboratory, and the adoption of such methods is made only after a thorough study of the results obtained by the Laboratory. It is sometimes found desirable to extend these investigations to the field, where the tests are made under working conditions before the methods or materials are included in the specifications.

The full value of a bureau of this character is not reflected in the number of tests completed, nor in the rejections of unsuitable material. The Testing Laboratory was not established as a detective agency to discover defects in materials and construction after the work had been done, but to assist the producers of material, the contractors and the County in obtaining satisfactory materials, and in properly incorporating them into the work. Rejecting an unsatisfactory material is a negative procedure, involving loss and trouble to all concerned. The prevention of the shipment of such material to the job is constructive co-operation. This does not mean that the county inspector always tests and approves materials before they leave the plant of the producer, but, through co-operation with the producer, he is given to understand exactly the quality and kind of material required for the county projects and usually his own inspection forces can prevent the shipment of material which would be rejected after arrival on the job.

The activities of the Bureau of Tests and Specifications extend throughout the Department of Public Works, but with reference to bridge and road construction the duties are briefly as follows:

1. Preparation of specifications for materials used in construction and correlation of these specifications with those of other bureaus using the same material.

2. Approval of subcontracts for all materials, and also of all subcontractors using materials for construction.

3. Complete mill and shop inspection of all steel, bronze, malleable castings and other materials used in highway bridge construction.

4. Laboratory investigations for materials to be used for special purposes such as paint, non-rusting metals, waterproofing materials, and aggregates, and writing of specifications covering such materials.

5. Co-operation with construction engineers in the field in connection with the setting of batcher plants, obtaining proper temperature control for winter construction, and the testing of concrete specimens at the various intervals necessary for the proper control of the job.

6. Co-operation with the inspectors of the construction divisions working in the field concerning methods of testing materials and aggregates in the field.

7. Plant control of materials, proportions, and mixtures of asphaltic concrete made by the County's own plants and by contractors' plants for the construction of bituminous wearing surfaces for bridges and roads.

8. Drilling cores from all pavements to determine if the proper depth of road slab has been obtained and making a report for the County Controller in connection with his approval of the final estimate for payment.

In discussing the work done by the Department of Public Works of Allegheny County in the control of materials for construction I do not wish to give the impression that the Bureau of Tests and Specifications, of which I happen to be the head, does the whole of this work. Under no circumstances is this true, for there is the fullest co-operation among the various bureaus involved in the construction of a given project. The field engineers are probably more concerned with the quality of the materials going into their work than any one else, and under the method used by us the inspection of fine and coarse aggregates is made in the field by members of the particular construction division, with equipment furnished by the Testing Laboratory. The field engineers make it their business to see that materials which can not be inspected in the field, such as structural steel, cement, castings, bituminous materials, paint, and wire rope, are not accepted unless they bear seals or tags stamped by the Bureau of Tests

and Specifications. In case of controversy in the field concerning the suitability of aggregates, the Laboratory is immediately notified by the field engineer and a test is made under laboratory conditions. In addition to the field tests made on aggregates, representatives from the Laboratory also select weekly samples of cement and aggregates which are taken to the Laboratory for routine tests.

During the past few years Allegheny County has built a large mileage of wire-rope barriers which have proved very satisfactory in the prevention of serious accidents and in the loss of life. Before this type of barrier was adopted, an extensive study was made in conjunction with the United States Bureau of Public Roads and the Pennsylvania State Highway Department. It was found that it was necessary to have drop-forged eye-bolts and reinforced concrete dead-men to withstand the terrific impact from a rapidly moving automobile or truck. It was also found that in burying the dead-man the ground should not be disturbed on the side next to the end post and that the heavy eye-bolt should be placed in a narrow channel rather than in a large trench. Particular attention is called to the dead-man, for that is the portion of the barrier which really protects the motorist in case of skidding. These tests showed that the posts serve as supports for the cables, but that the strain comes on the dead-men at the ends of the barrier.

It was also found from these tests that if the cables were placed at some distance from the post by means of an offset block, the hubs of the machines tended to slip past the post without knocking it out. This type of barrier was adopted by the County after an extensive series of tests made by the Pennsylvania State Highway Department in Harrisburg. The point which I wish to make is that in the adoption of the type of barrier which is being used by Allegheny County the engineers were guided by actual results of tests made on such barriers under service conditions so that when actually constructed the behavior of the barriers was all that could be desired.

The weight of coating used on all such wire rope or cables is 0.8 of an ounce per square foot of wire surface, in addition to which the customary Preece test of three immersions for one minute each, and one immersion for one-half minute is specified.

This weight of coating was adopted after an extensive study had been made of the necessary amount of zinc coating for durability

under local conditions. This amount of spelter is about as much as can be carried by barrier cable wire, and it has since been adopted by most of the state highway departments as a standard requirement for weight of coating.

It was found desirable to have bridge railings made of a non-rusting material similar to cast-iron but with greater physical strength and, after an extensive study of the problem, malleable cast-iron was selected. The specifications for malleable iron hand-railing material are in excess of the present requirements of the American Society for Testing Materials, and great care is taken to see that these high requirements for physical strength are maintained at all times. In addition to the tests made on samples taken from each heat, the finished posts have been subjected to drop tests made with a heavy block of iron like a skull-cracker. There have been a number of accidents due to the skidding of fast-moving trucks into these malleable iron hand-railings, but up to this time it has not been necessary to replace any of the malleable castings. It has been necessary to remove and straighten some of the structural steel members to which they were fastened, after which the malleable castings were straightened and used again.

Your attention is again called to the fact that the adoption of this type of barrier was not until after a thorough study had been made by the engineers of the Department of Public Works as to the suitability of malleable iron for this purpose, and specifications drawn accordingly.

In connection with the approval of the source of supply of concrete aggregates a study is made of the plant, and of the materials proposed for approval. For example, all limestone used in the construction of highways must come from an approved source of supply. Now and then one encounters a quarry in certain localities in which some of the stone is not durable.

Fig. 1 shows a retaining wall made with unsound limestone in one section and a sound and durable limestone in the adjacent section. This wall was built in Greene County about 1920 and all of the conditions of materials, methods of construction, etc., were identical, with the exception that it was decided that the limestone being used was not durable and the source of supply was changed. The illustration shows very clearly the failure of that portion of the wall made

from unsound aggregate. A section of highway built at the same time also disintegrated, due to the unsound limestone, after a period of about six years. A study was made of the quarry from which this particular stone was shipped, and a petrographic examination disclosed the presence of a clayey material known as beidellite. A chemical analysis of this particular limestone did not reveal its unsoundness and the results of physical tests were higher than those of average limestone.

It was found necessary for the County to refuse approval of a quarry in another adjoining county because of the fact that several

Fig. 1. Retaining Wall Built Partly with Unsound Limestone as Coarse Aggregate.

layers of stone in the quarry were unsound. Other layers of stone were entirely satisfactory, but it was impossible to quarry the good stone without mixing it with the unsound stone. In view of the fact that a very large amount of local capital had been invested in this particular quarry it was necessary that we be quite certain that the material in the quarry was not suitable for concrete construction. I do not wish to emphasize unduly the matter of unsoundness in limestone, because all of the quarries on the approved list of the Pennsylvania State Highway Department have been found to be entirely satisfactory, but nevertheless there is always a desire on the part of

contractors to use a local material whenever it is available. Our experience is that practically all of the limestone found in Allegheny County is unsuitable even for French drains, as it lacks durability when exposed to the weather. It is necessary to exercise considerable caution to prevent the use of such material in construction work.

All field engineers are furnished with the equipment shown in Fig. 2. The container marked "7" is of a diameter sufficient to permit the screens to drop down inside of it for convenience in carrying,

Fig. 2. Concrete Inspector's Field Equipment.

and the height is exactly 10 inches. The container is first filled with a representative sample of the coarse aggregate, after which the material is dumped into a wheelbarrow and screened carefully back into the container, starting with the smallest size of screen opening. Every inch of material going into this container represents about ten per cent. passing that size of screen. In view of the fact that our specifications have rather wide limits, we feel that this method of determining the percentage of coarse aggregate passing a given size of screen is sufficiently accurate for field purposes since it is also used in

conjunction with a careful observation of the general grading of the car or barge of material.

Materials inspected at the source of supply are labeled in various ways. Fig. 3 shows the method used for marking paint after it has been approved. All paint used by Allegheny County is made in accordance with our specifications and the raw materials are inspected and tested in our Laboratory before they are incorporated into paint at the plant of the manufacturer. After the paints have been ground, a representative from the Laboratory sees that the paint is placed in

Fig. 3. Official Label.

the containers and properly labeled with the "Inspected" label bearing the monogram of the Laboratory shown in the circle at the bottom of the diamond-shaped label. This mark is not placed on the label until after the material has been finally approved, and blank labels without the official monogram are not accepted by the engineers in the field. This same diamond-shaped label is also used for marking the reels of wire rope and any other materials on which such a label can be pasted.

From every day's run of concrete, the inspector in the field makes concrete cylinders, six by 12 inches in size, and for paving

jobs he frequently makes concrete beams six by eight inches, and 40 inches in length. These beams are made at intersections and other points where it is desired to open the pavement or bridge approach at an early date. The beams are cured in the same manner as the pavement, and when they are ready to be tested the Laboratory sends a truck with a beam-breaking device, such as is shown in Fig. 4. The length of the beam of the testing-machine is such that the load applied at the end gives the modulus of rupture of the concrete beam tested as a cantilever without additional computations.

Fig. 5 gives the data for determining the maximum weight of vehicles which may pass over the pavement slab for any given

Fig. 4. Beam-Breaking Equipment Attached to Bureau Truck.

modulus of rupture as determined by tests of beams. These figures are based on the well known formula for thickness of pavement slab as given in a paper by A. T. Goldbeck, presented before the Society in 1925.*

The specifications of Allegheny County provide that, immediately after signing the contract, the contractor shall submit in writing information indicating to whom he proposes subletting any portion of the contract either for material or for labor. Officially the County does not deal with the subcontractor, but with the main contractor,

*Proceedings, v. 41, p. 157.

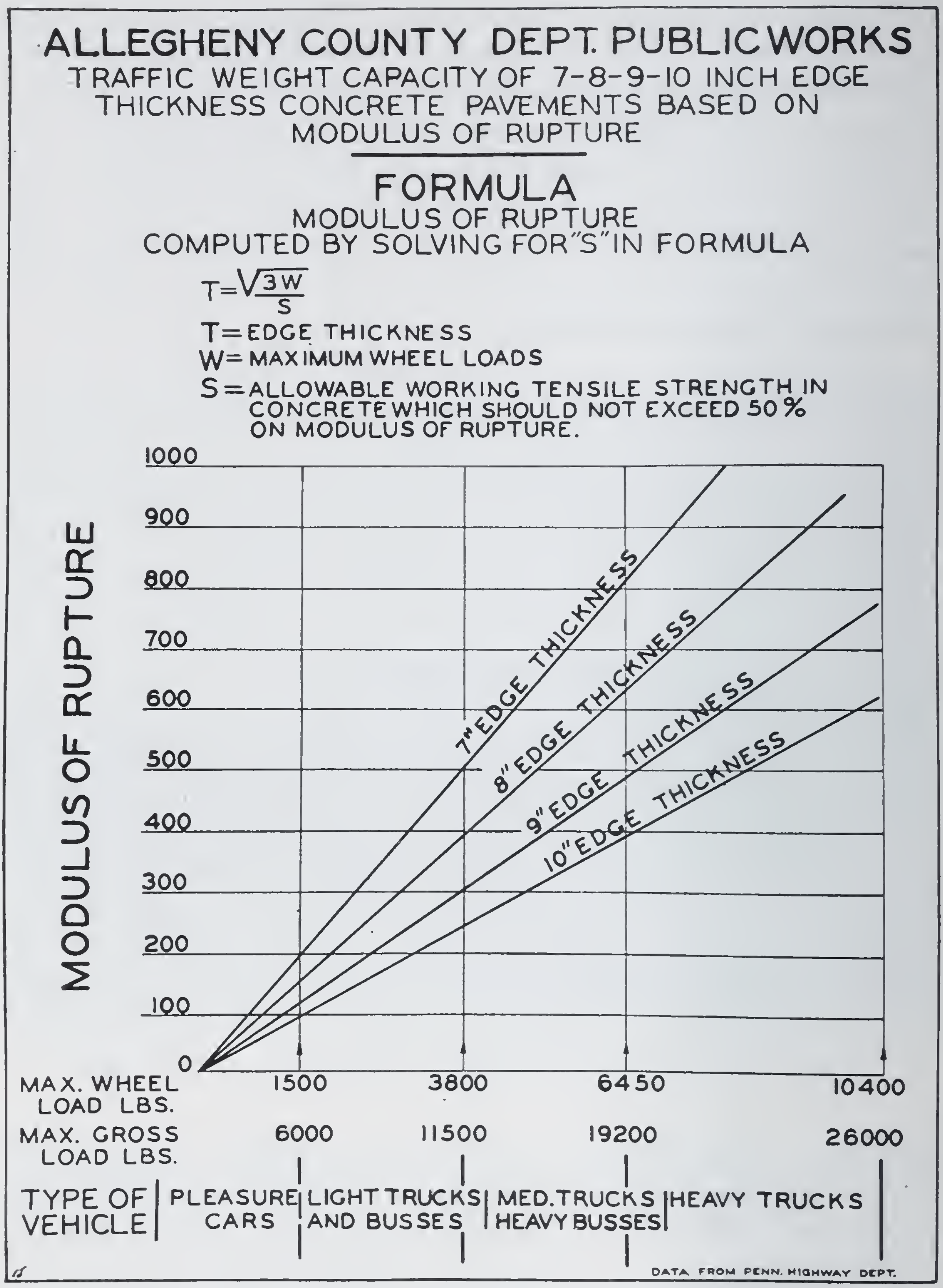

Fig. 5. Diagram Showing Permissible Loading for Various Thicknesses of Pavement.

who is under bond with the County. In actual practice, however, we have our ordinary dealings directly with the subcontractor and the producer of material. This method is pursued as long as the pro-

ducer of material or the subcontractor is co-operating with us and furnishing satisfactory material. If he fails to do this, the subcontractor is immediately ignored and pressure brought to bear on the main contractor, which may require him to obtain a new source of supply.

The specifications further require the contractor to furnish representative samples of materials before placing his orders, and to obtain permission to purchase materials from any particular source of supply. If the proposed source of supply is one which is well known to the Bureau of Tests and Specifications no samples are required and permission to purchase from that source of supply is readily given in writing, with a duplicate copy to the field engineer.

It is our belief that great stress should be laid upon having the contractor place his orders with companies which are fully equipped to furnish materials complying with specifications. New sources of supply are always welcome, and investigations as to the capability of any producer to furnish satisfactory material are gladly made without charge.

The key-note of this combination for the enforcement of material specifications is to see that, before being certified, all subcontractors and material producers definitely understand the requirements of the specifications. If all parties thoroughly understand the requirements in advance of signing their final contracts, a great deal of unnecessary inspection trouble is eliminated.

The specifications further require that after "the approval of source of supply of material has been obtained the contractor shall furnish two copies of the order for his material to the Bureau of Tests and Specifications. All orders shall carry the notation *this material must meet the requirements of Allegheny County and is subject to inspection by the Bureau of Tests and Specifications.*"

At the time a project is advertised it is given a consecutive job number which covers the contract throughout the period of its existence, and the contractor is instructed to use this number on all orders and in correspondence with the County regarding the contract. All samples of every kind connected with that contract carry the job number in addition to the number of that particular sample. This simplifies clerical work in the office and makes it impossible to confuse samples from jobs having similar names.

Immediately upon receipt of copies of these orders, an engineer in the Bureau of Tests and Specifications goes over them to see that the orders actually call for the kinds of materials required by the specifications. Since no shipments have been made, it is an easy matter to correct errors made by the purchasing agent of the contractor in placing the orders. The contractor is advised that he should eliminate the prices from the copies of orders sent to us, as we have no interest in the actual prices being paid by any contractor, but are concerned only with having the orders to expedite the inspection of materials.

If the orders are correct in all details, one copy is furnished to the inspector who will handle that particular material at the source of supply or at its delivery point. If the order is such that other subcontractors are involved in the delivery of materials, they are, in turn, required to obtain approval of their sources of supply and also to furnish copies of their orders for all materials or orders to subcontractors.

The process involves a considerable amount of correspondence previous to the actual inspection of the material, but, since it is handled by thoroughly trained engineers who are familiar with the sources of supply, and with the conditions in practically every foundry, mill, and shop within shipping distance of Pittsburgh, there is no delay in granting approval of subcontractors.

In order to have a record of all projects before the Bureau engineers, a large sheet has been developed which carries headings covering the job number, name of job, name of contractor, date on which he is notified to get in touch with the Bureau, and date on which his first reply is received. Following these columns there are headings to cover every kind of material used in construction work. A mark is made in the proper column for the materials to be inspected under that particular contract. As soon as inspection has started on that contract, a second notation is made in that column to show that a particular material is being properly inspected. This sheet shows at a glance whether or not any materials are being overlooked. It has been found that materials which are not great in quantity may be overlooked by the contractor in placing his orders and he may need such materials at the last moment. We have found it to be to our mutual advantage to check over the sheets and see that materials such as a drum of crack filler be ordered in time to allow for ade-

quate testing before it is needed. In this way we not only help the contractor, but assist the field engineer and make it unnecessary to hold up construction until a given material may be tested. All that we ask is a reasonable amount of co-operation from the contractor.

The point which I wish to emphasize is that the actual physical labor of inspecting materials, both in the shop and the field, is greatly reduced if it is necessary to reject only the ordinary amount of materials usually found below standard in the average operation of a well equipped plant. Since no plants are approved as sources of supply unless it is known that they are capable of furnishing the material, and such approval has not been given until the engineers of the plant have been interviewed and the requirements of the specifications thoroughly discussed, the amount of actual rejection by our inspectors has been cut to a minimum.

Copies of all correspondence with the contractor concerning materials are sent to the resident engineer in the field and, unless he has positive information by means of tags or reports, he is instructed to assume that such materials have not been inspected before they arrive on the job.

An endeavor is made to assist small subcontractors and producers of material to build up a business, and in some cases approval will be given for placing a contract with a company which is not equipped to handle the entire amount of the work if this company, in turn, agrees to sublet a portion to another subcontractor who is fully equipped to do the work required.

In order that there shall be no delay in actual field work, it is our policy to keep the testing done ahead of the needs for material. A contractor can hardly be blamed for being peevish if he has to wait several days for inspection of material which he needs very badly, and if such a situation is common there is danger that the resident engineer and the contractor will both decide to use the materials without inspection.

I believe that the failure of municipal testing laboratories to keep the material inspected well in advance of the need in the field is responsible for a large part of the difficulties encountered in the handling of such inspection in various cities. On the other hand, it is impossible for the inspection bureau to inspect and test materials unless the source of supply is known and copies of the orders are

available for use by the inspectors in locating the materials at the plants. It is for this reason that we found it necessary to insist that the contractor comply strictly with the requirements of the specification in regard to obtaining approval of source of supply and in furnishing of copies of his orders.

Now and then a contractor will fail to place his order in advance and if this happens we endeavor to co-operate with him to the fullest extent, but we do not feel that he is entitled to any particular sympathy if his job should be shut down until standard tests can be made on the materials which have not been tested and approved.

It will not be possible, or worth while, to go into details concerning methods used for the inspection of steel bridges in the mill and shop. General methods used are the same as those followed by reputable testing laboratories, railroads and other municipalities. Reports covering such materials are made out in pencil and copies transmitted immediately to the construction bureau involved. No attempt is made to type-write such reports, as it is felt that their value is increased if the construction engineer receives such reports without delay.

In the inspection of heat-treated eye-bars for bridge construction, a number of the bars were given a careful Brinell test at short distances along the entire length and breadth, and these bars were then pulled to destruction to determine the actual tensile strength and other physical characteristics for that particular Brinell number. The testing of several such bars established Brinell limits by which the actual ultimate strength of full-sized eye-bars could be predicted. Small test-pieces do not give this information. Having established a Brinell limit it was only necessary to make Brinell determinations on each eye-bar to enable us to have positive assurance that every eye-bar conforms strictly with the tensile strength called for by the designer.

Fig. 6 shows the equipment which is used by our inspectors at the asphalt plants owned by Allegheny County and also used at plants operated by contractors for bridge floors and pavements. All of this equipment fits into a large box, and at least two extra sets of equipment, together with all the necessary blanks, carbon paper, pencils, etc., are locked up ready to be shipped to a contractor's plant immediately upon receipt of notice. An inspector from the Testing

Laboratory tests every car of sand, stone, or slag immediately upon its arrival at the asphalt plant, and the shipment is accepted or rejected immediately. After these separate materials have been approved they are fed into the plant and dried and screened into appropriate bins. Samples from these hot bins are carefully graded by the inspectors and from the results the proper mix is established. The plant scales are then set and each size of aggregate and the amount of asphalt cement weighed separately into the hopper.

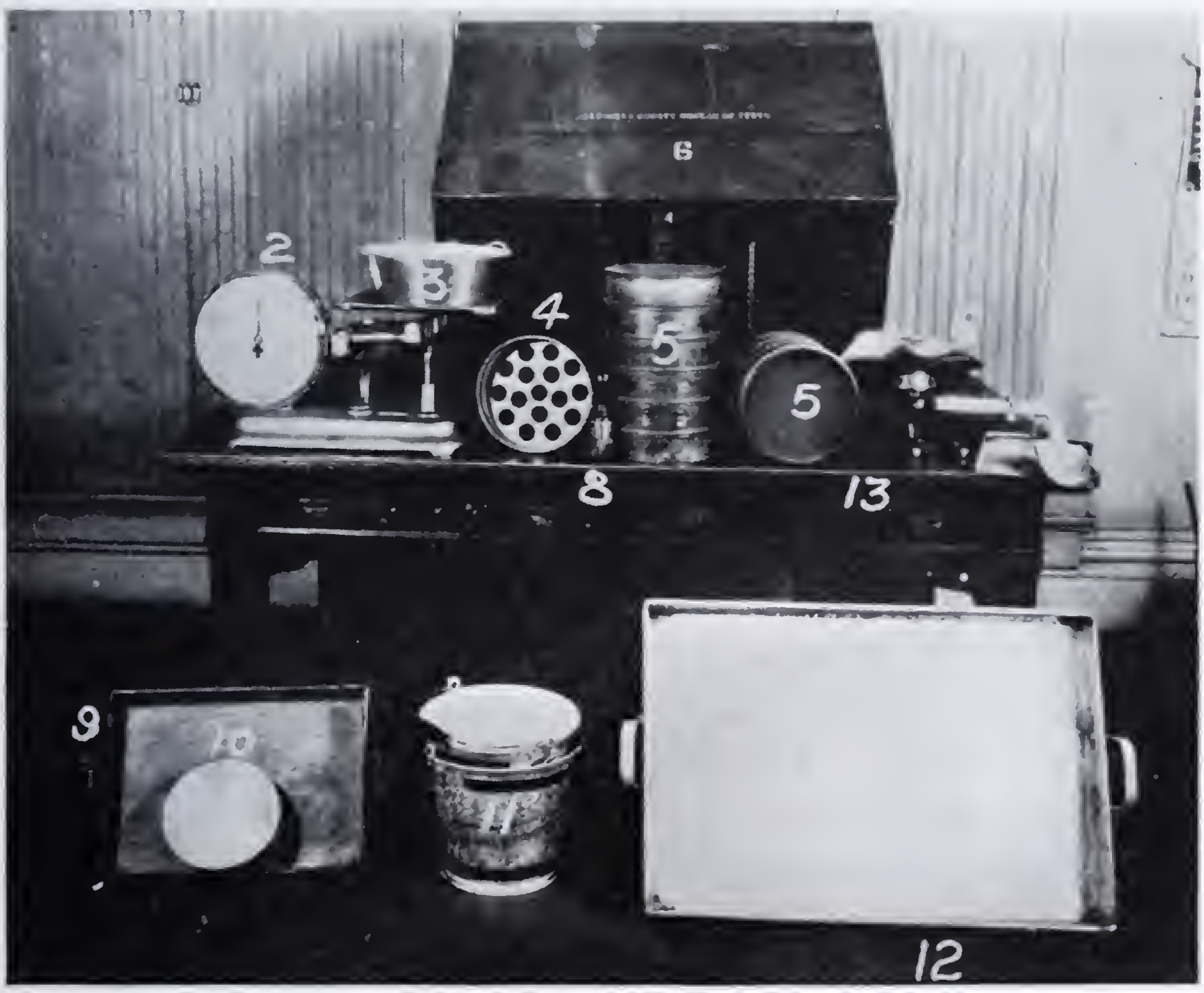

Fig. 6. Equipment for Inspectors at Asphalt Plants.

The five Allegheny County asphalt plants are equipped with recording pyrometers and thermometers which make permanent records of the temperatures of the various materials put into the asphaltic concrete.

Samples of all shipments of asphaltic cement are rushed to the Laboratory, together with daily samples of completed mixture. Fuel-oil and asphaltic cement are held in the tank-cars until a report is telephoned from the Laboratory that they comply with the specifica-

tions. In the control of materials at a contractor's plant the same procedure is followed.

It was found that, after the amount of bitumen had been extracted from the asphaltic concrete in which stone passing 1¼-inch screen was used, the percentage of bitumen did not check with the amount which had been actually weighed into the mixture at the plant under the eyes of our inspectors. A careful study was made of the whole problem, the results of which were first published in the *Engineering News-Record* of September 23, 1926 (page 513), and in Circular 49 of the Asphalt Association published in 1927.

The daily samples of the finished mixture when brought to the Laboratory are placed in specially constructed extractors which operate during the night. The next morning the aggregate is graded and the total superficial area per hundred grams is taken from a weight chart which we have prepared for the particular coarse aggregate being used by the County. The bitumen actually found by extraction is compared with the amount required for a perfect mixture by the same aggregate which carries it. This method of correcting laboratory results has shown the importance of obtaining a sample which truly represents the entire mixture. In view of the fact that the surface area of a cubic inch of sand is at least forty times as great as the surface area of a cubic inch of stone it is readily seen that if a small amount of stone in excess of what would make a representative sample is present in the material placed in the extractor, the result obtained by the Laboratory is deficient in bitumen. By our method we have been able to check the Laboratory samples closely against the reports of our field inspectors at the plants.

Early each morning the results of the tests made on the previous day's output from every plant are studied by an experienced engineer; any variation from the standard is noted, and the necessary changes in procedure are telephoned to the plant concerned.

The engineers in the Department of Public Works are members of the various technical societies and are permitted to attend committee meetings and conventions of engineers throughout the country. I feel that the engineers in the Department of Public Works should congratulate themselves on the freedom with which they are permitted to attend such meetings, but on the other hand, the information disseminated through activity on committees and contact with other

members of the profession is of inestimable benefit to the County in the development of engineering knowledge, both as to specifications for materials and methods of construction of roads and bridges.

DISCUSSION

C. N. HAGGART, *Chairman:** We all appreciate this paper that Mr. Freeman has given us, and I hope any who wish to do so will be free to discuss it or ask questions.

S. A. TAYLOR:† I think you said that no stone in Allegheny County is satisfactory for use in concrete.

P. J. FREEMAN: That relates to limestone; at least we have never found in this county any that would be safe to use. There may be a little in some isolated places, but in general I think you will find conditions exactly as stated. It will be hard, you will blast it out, but if you let it lie along the road it will have disintegrated within a year. This is not shale, but real limestone. Sandstone is in a different class, and is used to a slight extent for concrete.

S. A. TAYLOR: Not so much for concrete as for masonry.

P. J. FREEMAN: Sandstone in the Pittsburgh locality is generally not very good for masonry. We have sandstone quarries from which the stone in structures at the end of 25 or 30 years has disintegrated considerably. There are a number of examples around Carnegie. We generally have to go to other districts to get our sandstone.

S. A. TAYLOR: I think that is very true in the southern section of Allegheny County. When you get north of the Allegheny River there is a very good sandstone.

P. J. FREEMAN: We have never been able to get it in commercial quantities.

V. R. COVELL:‡ Allegheny County is very deficient in good building stone and I know of no quarry where sandstone of good

*Consulting Structural Engineer, Pittsburgh.
†Consulting Engineer, Pittsburgh.
‡Chief Engineer, Bureau of Bridges of Allegheny County, Pittsburgh.

quality is produced in a commercial way. Some good sandstone has been obtained from Rocky Ridge, about 1400 feet above sea-level near Library, Pa., and in former years sandstone boulders of high quality, found in the eastern part of the county, have been split up for bridge masonry. Many of the older bridges were built from local sandstone of an inferior quality. An examination of such masonry will show one stone in good condition while the stone beside it will be so weathered as to show no tool marks.

A. W. Worthington:* I want to clear up one point. You mentioned adjoining counties, as well as Allegheny County. You do not mean to discount the value of the Vanport limestone in Butler, Armstrong, and Lawrence counties?

P. J. Freeman: No. I think I named Washington County, and there is some in Westmoreland County. The limestone around New Castle is especially good. The stone that is being used in Allegheny County work is almost equal to trap-rock as far as abrasion losses are concerned.

M. H. Henry:† Our tests and investigations of local deposits of stone show that all those examined failed to meet our specification requirements with the exception of the band of limestone commonly known as the Ames limestone. However, this stone is found only in a thin bed, approximately three feet in thickness and overlaid with from 50 to 150 feet of overburden which precludes its use commercially. It can be found at the sidewalk grade approximately at the Second Avenue entrance of the Armstrong tubes.

J. J. Paine:‡ I would like to say that our laboratory bears the same relation to the City that Mr. Freeman's does to the County. Our conditions are different in many ways, and in some cases they are very similar. Our pavements are almost always covered with something—block stone, brick, or bituminous material of some kind—and conditions of that sort make our work a little different from that of the County. We have tried to work together and make specifications

*General Manager Pittsburgh Limestone Co., Pittsburgh.
†Materials Engineer, City of Pittsburgh Laboratory, Pittsburgh.
‡Chief Engineer, Bureau of Tests, City of Pittsburgh, Pittsburgh.

as nearly the same as possible so as not to work a hardship on the producers, not only in concrete but in everything else. Our laboratory tries, as far as possible, to use the specifications of the American Society for Testing Materials. Mr. Henry, who just spoke, has charge of the concrete materials. Mr. Reed is here and I believe he will have something to say.

THOMAS REED:* I am guided by Mr. Paine's research just as Mr. Freeman guides the County bureaus. Our field men work very closely with Mr. Paine's men. We have been trying to get results such as Mr. Freeman has outlined. I believe that in the past four or five years both the County and the City have benefited, as far as both the producers and the taxpayers are concerned.

V. R. COVELL: I have been connected with the County bridges for a great many years and, previous to the formation of the Department of Public Works and the creation of the Bureau of Tests and Specifications, we were largely dependent upon the commercial inspection bureaus. As Mr. Freeman has stated, there is no discount on the work that these commercial bureaus could do, yet those of us who have had experience with the County work know how much more efficiently this work can be carried on when we have our own inspection bureau to which we are free to go at any time and with which we can co-operate more fully.

I want to testify to the fine co-operation we have had during these years from the Bureau of Tests and Specifications. I do not see how we could possibly have carried on the work as rapidly as we have done had we not had its valuable assistance. It may be interesting to know that during the last year we had 36 different bridges under construction, 27 of which were completed.

C. N. HAGGART, *Chairman:* I think it has been evident to those who have observed the matter that there has been very fine co-ordination between the Bureau of Tests and Specifications and the construction and designing engineers.

There are numerous illustrations of the variability in the quality of construction of engineering works. One reason for this is lack of

*Chief Engineer, Bureau of Engineering, City of Pittsburgh, Pittsburgh.

engineering control during construction. As an example, we know that there is a considerable difference in asphalt pavements. We have in Mt. Lebanon, on Washington Road, a good asphalt pavement constructed on a narrow road. Later the road was widened and the added width also paved with asphalt. This latter pavement is not nearly as good; it has been resurfaced within the last few years, but already is in worse condition than the original pavement. Mr. Freeman is probably familiar with this pavement.

P. J. Freeman: Yes, but the County did not have anything to do with it.

R. V. Warren:* As an engineer representing producers of aggregate, I agree with Mr. Freeman's statement that it is wise for engineers to look elsewhere for specification data, particularly when it comes to specifying the grading of aggregates. It seems to me that many engineers want to be original; they don't care what the other fellow is doing. As a result, the producers of aggregate are asked to meet a multiplicity of gradations.

A recent study of current specifications for highway work, furnished by the Pittsburgh sand and gravel producers, disclosed 51 separate gradations for coarse aggregate. There were 28 gradations for concrete work—10 for large-size aggregate; 10 for medium size; and eight for small size. Isn't this the result of being original and the failure to seek information elsewhere on what other engineers are specifying?

F. M. McCullough:† I believe that this Society a few years ago adopted specifications for concrete aggregates. To what extent are those specifications followed?

P. J. Freeman: I think you will find that in general we are pretty close to those specifications. On the other hand, we follow implicitly the specifications of the Pennsylvania State Highway Department, which is the largest consumer of aggregates in the state. We can find more available material adapted to the state specifications.

*Engineering Representative, Western Pennsylvania Sand and Gravel Association, Pittsburgh.

†Professor of Civil Engineering, Carnegie Institute of Technology, Pittsburgh.

M. H. HENRY: Mr. McCullough's query can be answered by saying that the Society specifications covered a general field, including building construction, railroad construction, highway construction, tank construction, and reservoir construction, and was intended as a starting point or guide to engineers in working out specifications for specific construction.

A. A. LEVISON:* One of the points mentioned by Mr. Freeman (a new development in concrete construction, a practice which is spreading rapidly throughout the country) is the division of the coarse aggregate into separate sizes and the recombination of these sizes, batch by batch, on the job. Mr. Freeman brought your attention to this in his paper but, due to the broad and varied scope of his discussion, he did not enlarge on this subject.

This new departure in specifications for concrete is a good illustration of why it is difficult to stabilize specifications. New ideas creep into our construction practices, and result in improved quality and economical production. As soon as this happens, specifications undergo a change in order to take advantage of the new ideas.

Locally, we are faced with this situation in concrete construction and it is going to affect us definitely sooner or later. The United States Bureau of Public Roads has taken a very definite attitude in recommending the division of coarse aggregate into separate sizes. This means shipping to the job separately, piling them separately on the job, and then recombining the separate sizes in the proper ratio at the proportioning plant. This immediately brings about, to some extent at least, a new specification for the gradation of the aggregates. This practice of dividing coarse aggregates into separate sizes has been established in California for a good many years. More recently it has become accepted practice in the highway departments of New Jersey and North Carolina. In 1931, the highway departments of New York and Vermont are adopting this new specification. I do not believe the State Highway Department of Pennsylvania will take any definite action on this new specification during 1931.

It has been proved, in a measure at least, that the control of concrete, prior to placing, has been improved by dividing the coarse aggregate into separate sizes. This scheme makes it possible to im-

*Chief Engineer, Road Department, Blaw-Knox Co., Pittsburgh.

prove the uniformity of yield of the concrete per unit of volume of cement; also to improve the uniformity of the workability and consistency from batch to batch.

I take this opportunity of emphasizing this point in Mr. Freeman's paper because we are going to be confronted with it in the near future. In this connection, I have noticed that in the work of the highway department of North Carolina, where this division of coarse aggregate into separate sizes has been practised for several years and where they have a different specification for each size of coarse aggregate, these include ¼ inch to ¾ inch; ¾ inch to 1½ inches; 1½ inches up to the maximum size, which is usually 2¼ or 2½ inches, and, while the materials, as delivered on the job do not always conform 100 per cent. to the gradation specification, the engineers in charge are able, when using separate sizes of coarse aggregate, to make a sieve analysis of each size as it is in the stock pile and adopt the proper proportion for each size so as to get a combined grading which is satisfactory.

This new specification may, in some localities, require changes in the screening equipment at the producing plants, and this new method in control of concrete will have its effect on the producer, the contractor, and the engineer in charge of concrete construction.

C. N. Haggart, *Chairman:* Is there a paint man here? Perhaps a paint manufacturer would have something to say.

J. E. Staud:* I must say that the method of inspection as established by the County has been entirely satisfactory to the paint manufacturers in this district.

The manufacturer is at all times eager and willing to co-operate with the consumer and give him the benefit of his knowledge and experience. The result of this spirit of mutual co-operation is increased confidence and improved products. The high quality of the paint products supplied to the County is ample evidence of the success and value of the present method of inspection.

C. N. Haggart, *Chairman:* We have not heard anything from the foundrymen.

*Chief Chemist, Lawrence Paint Co., Pittsburgh.

Frank J. Lanahan:* I interpret the Chairman's remarks as an invitation for further discussion. I could approach the subject from three different angles; first, as a member of the Engineers' Society of Western Pennsylvania, and express approval of the efficiency, sincerity and capability of the speaker of the evening; second, as a member of the Board of Directors of the National Safety Council, I was glad to hear the suggestion for the elimination of hazards through the mechanism of the testing laboratory. It is fine to observe the trend of safe thinking. Another angle from which I view the paper is as a resident and a taxpayer of Pittsburgh and Allegheny County. From this viewpoint, it was gratifying to learn of the measures that are being taken for the protection of the people's interest, and it does seem a pity that a larger number of the population of Allegheny County could not be here to listen to Mr. Freeman's splendid presentation of a subject vitally important to all taxpayers, and thus comprehend the protection that is thrown around the material that is purchased and the efforts made to get true values for every penny expended.

It has been interesting to listen to the discussion. It has been an enjoyable evening, but confidentially, as a manufacturer of malleable iron, I am just a little disappointed. A lot of us came up from the Fort Pitt Malleable Iron Company with the expectancy of hearing Mr. Freeman relate his experience with malleable iron and how it has functioned in the various severe tests to which he has subjected the different sections that were applied to bridges and highways in Allegheny County. We realize that the speaker had a wide field to cover and was thus denied the opportunity of particularizing on any phase of his problem.

In passing, it might be apropos to state that our relations with the Bureau of Tests and Specifications are of comparatively recent origin, but we have found the members of this Bureau thoroughly efficient and eminently fair. So equitable were our relations that we never perceived any difference between the Bureau, the architect, and the engineers during the progress of our work. Every one, from Director Brown to the humblest inspector, exhibited a splendid spirit of co-operation, and was exceedingly helpful in working out this new function for malleable iron. While very close scrutiny is maintained

*President, Fort Pitt Malleable Iron Co., Pittsburgh.

on the analysis of the material, the molding of the castings, and the supervision of the tests, this was done most intelligently and with every consideration that circumstances and conditions would permit.

It would be very gratifying if our citizens as a whole could have this subject presented to them in even a more elaborate way than has been done before you engineers to-night. It would be well to have all realize the efficiency of the Department of Public Works of Allegheny County.

OIL MINING FOR THE PENNSYLVANIA FIELDS*

By Leo Ranney†

Introduction. Can oil of Pennsylvania grade be produced, by mining, at a lower cost per barrel than by present methods of production? Can a larger quantity of oil per acre be recovered? Since a certain amount of Pennsylvania oil is, and will be, required, can it not be produced at a profit even during periods of proration?

The history of the recovery of oil by mining operations has been related so many times that it is unnecessary to refer to it. Likewise, oil-mining experience at Péchelbronn in Alsace, at Wietze in Hanover, and at Jacksboro, Texas, has been ably presented in various articles by Rice and Davis,‡ Torrey,§ and others, so that a discussion of these installations will not form a part of this paper. Let it suffice to say that since a modified form of the process under consideration has been adopted at Péchelbronn, even though the oil sand there averages only four feet in thickness and, though systematic repressuring has not been applied, the percentage of recovery has been high and the profits satisfactory.

Probable Demand for Oil of Pennsylvania Grade. The discovery of new oil-fields in the South and the West has seriously affected the demand for the crude of most old fields, but, thanks to quality, there is no falling off in the use of Pennsylvania grade. There is only one Pennsylvania grade and the world knows it to be the best. As shown by Zook,¶ the demand for this particular oil has increased yearly at the rate of 3000 barrels daily to over 66,000 barrels, and, now that more of the larger companies are distributing and advertising Pennsylvania lubricants nationally, consumption should increase more rapidly in the immediate future than in the past. What the ultimate daily requirement of crude oil will be is difficult to predict, but it is probable that for some years to come the demand for this grade of oil will be upwards of 70,000 barrels a day.

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†President, Ranney Oil Mining Co., New York.
‡*Trans. A. I. M. and M. E.*, v. 74, p. 857.
§Pennsylvania State College, Mineral Industries Experiment Station, Bulletin 9, p. 19.
¶Pennsylvania State College, Mineral Industries Experiment Station, Bulletin 9, p. 65.

Cost of Production, and Probable Selling Price. Many years ago iron ore was produced profitably from low-grade deposits in New York, New Jersey, Missouri and elsewhere; but when the Mesabi Range in Minnesota was discovered, dozens of low-grade properties in other states were abandoned. It is the opinion of many oil men that the eastern oil-fields must go the same way as these lean deposits of iron ore, in the face of new discoveries. If this opinion is correct, it means that an investment of possibly a billion dollars in producing properties will be lost. I can agree with this opinion only if deposits of the equal of Pennsylvania oil are uncovered elsewhere, or if it becomes profitable to duplicate Pennsylvania lubricants from low-grade crude oil. The real menace to the Eastern producer lies not in the field but in the laboratory. In view of new processes of manufacture, one thing appears certain, and that is that Pennsylvania oil never again can long command such prices as prevailed several years ago, or even two years ago. I doubt whether we shall be fortunate enough to see the price stabilized at much above $2 a barrel. What I mean to say is that unless production costs can be lowered, whether you enjoy it or not, many of you may have to write your oil properties off the books.

The total cost of producing oil by water flooding in the Bradford field (including the cost of acreage) seems to run from $1.75 up to $3 a barrel. So far, water flooding has not been practised and proved in any other field than Bradford.

The cost of producing Pennsylvania oil naturally or by means of an air drive or gas drive outside of the Bradford field is extremely difficult to ascertain. It is estimated variously at from $2 to $4 a barrel, but since you gentlemen are more or less familiar with these costs, I shall not attempt to say what the average may be, except to remark that few producers are willing to claim that their total is as low as $1.50 a barrel. If the recovery of oil by mining can cut under this figure, it should have a place in the Eastern fields, and, if it can produce oil for $1 a barrel, it may be the salvation of properties which now have no hope of profitable operation. Oil producers are prone to remark that often, in times past, the Pennsylvania oil industry has been in the dumps, but always has recovered. This is true, of course, but never before has the scientist been able to manufacture from low-grade oils a lubricating oil as good as Pennsylvania. To-day

this is actually being done, and thus the cost of making such a product in modern plants is bound to set the price of eastern crude.

Distinguishing Characteristics of Eastern Oil Sands. In Mid-continent and Gulf Coast areas it is common to find porous sand bodies of considerable thickness without partings. The fields of Pennsylvania, West Virginia, New York, and Ohio differ from these essentially in the following respects:

1. The average thickness of the oil sands is less, and the sands lie closer to the surface than do the prolific sands of western fields.

2. The sands of the East have porosities ranging from 12 to 20 per cent., while in the West porosities of 18 to 26 per cent. are common.

3. Practically all eastern oil sands are stratified to such an extent that it is not unusual to find the upper, middle, or bottom part of the sand as much different in permeability as one would expect in entirely different fields.

Because of such differences between eastern and western sands it is essential that the methods of secondary recovery be adjusted to the peculiarities found. In the first place, the Appalachian sands are more accessible and may, therefore, be operated more intensively. Because of the low porosities, a more positive system of expulsion is required and, because of the stratified nature of the sands, gravity has only a small part to play, and the displacement of oil must be largely in horizontal planes.

Outline of the Ranney Process. By this method of mining oil a shaft is sunk to a point below the oil sand. The shaft may be small because the product is hoisted by pumping, instead of being taken out in bulk. It is necessary to seal the sands against the escape of gas, oil or water into the shaft. State laws require the sinking of a second shaft for ventilating and safety purposes. From the bottom of the operating shaft a system of tunnels and cross-cuts is driven about 20 feet below the oil sand, such operating tunnels being approximately six feet wide and seven or eight feet high, depending upon ventilation requirements, following subsurface contours where the sands dip steeply, but otherwise driven without respect to structural dips.

At intervals of approximately 20 or 30 feet, slightly inclined holes are drilled into the tunnel roof almost to the producing horizon. Into each hole a pipe or casing is grouted under pressure and to the bottom end of the pipe is attached a gate-valve and a stuffing-box. A rotary drill with a round shank is inserted through the gate-valve, the shank extending through the stuffing-box, and by means of a drill a hole is made from the end of the sealed-in pipe or casing into the oil-bearing sand. This open hole taps the sand at the desired point, and at that point it may be sprung with a light shot, or reamed to expose a greater sand area. When low pressures are used, if different pressures are desired in different levels of the sand, a device approximating a bradenhead may be applied in the mine well so that the pressure for any horizon in the sand may be adjusted to satisfy the permeability of that horizon. When the mine well has been completed, the stuffing-box is removed and the gate-valve left in place. If high pressures are used, the casing in each mine well may be braced to the tunnel floor.

Producing tunnels alternate with pressure tunnels so that a bank of oil is driven from each side toward the row of mine wells belonging to each producing tunnel. The casing of each mine well is connected to the oil-collecting pipe-line in the bottom of the tunnel. In each pressure tunnel is a pressure line carrying gas, air, or water from the surface of the ground, and each intake well is connected with this pressure line, the gate-valve on individual wells being used to control the amount of expelling agent allowed to enter the sand at that point. Pressure-gages and meters on occasional mine wells may be utilized to regulate the amount of oil expellant allowed to enter. The purpose is to maintain as nearly as possible a straight line for the repressuring agent, both horizontally and vertically.

Fig. 1 shows a cross-section of an oil mine designed for Pennsylvania fields. Water, gas, or air may be used to expel the oil from the sand. Test holes enable the operator to follow the advance of the expellant and to sample the fluid at any level.

Fig. 2 shows a proposed lay-out of an oil mine on an area of about 1000 acres where the structural dip is slight. The simplicity of haulage and ventilation is apparent. The shafts are approximately in the center of the tract, and the maximum haulage is about a mile.

In oil-mining operations it is proposed to make extensive use of the core-drill, because of the necessary information to be gained there-

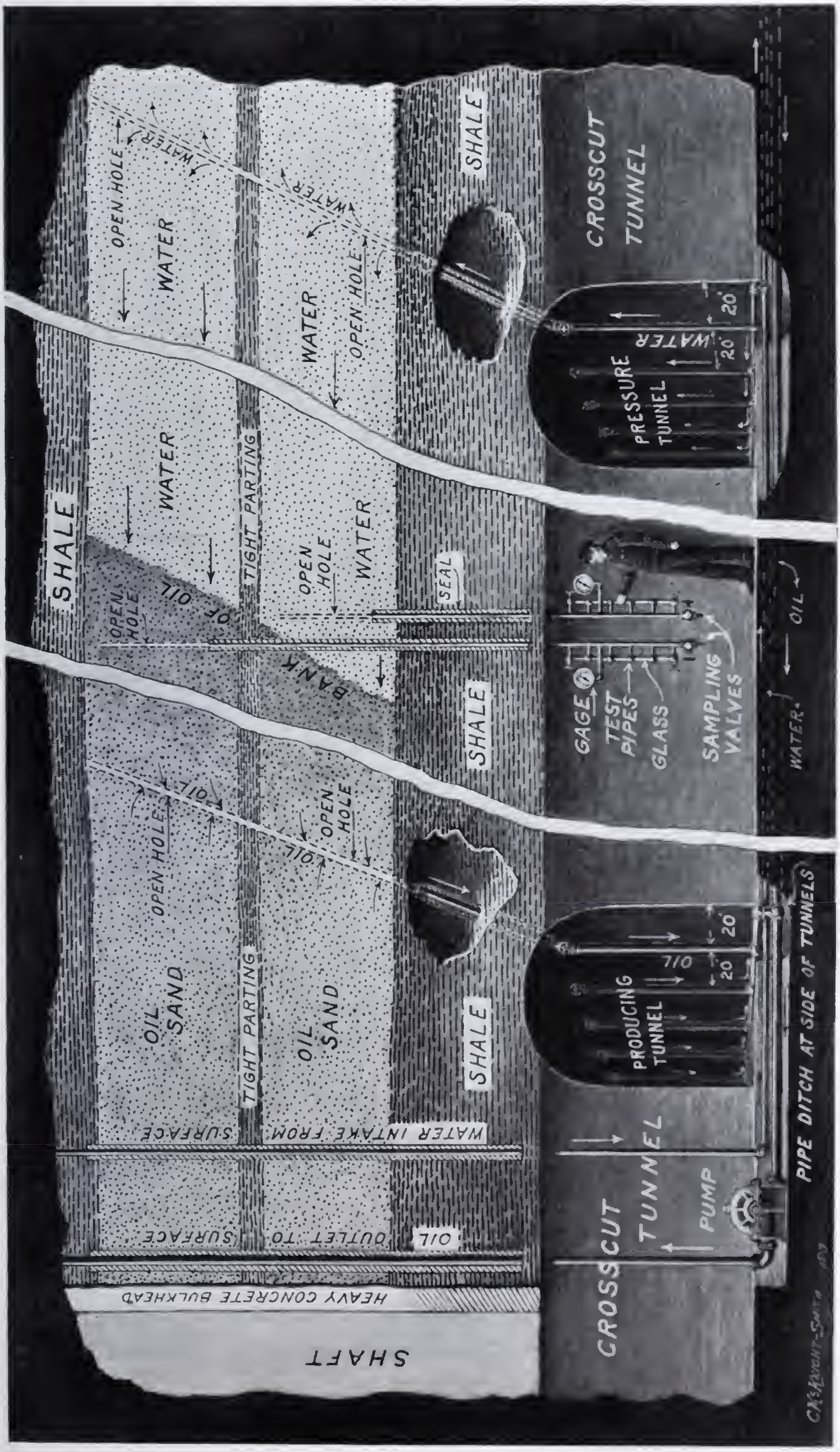

Fig. 1. Cross-Section of Oil Mine.

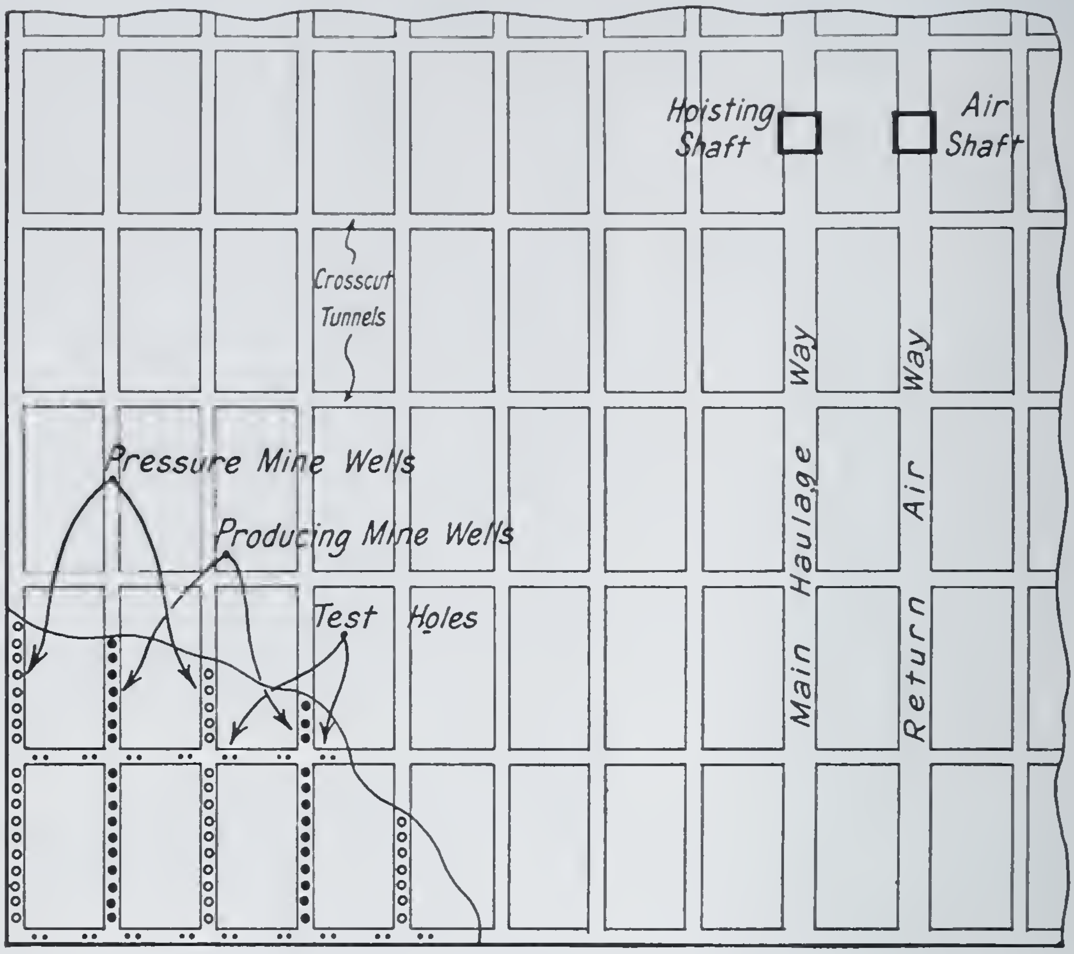

Fig. 2. Lay-Out of Oil Mine.

by. The taking of cores from mine wells is not an expensive operation because of the upward direction and the slight depth of the wells; and concurrently the utilization of the knowledge gained from a study of the cores is a simple matter because of the close proximity of the operator to the sand. All mine wells are drilled with a machine mounted on a car which runs on a track along the tunnel. In shale below the sand an augur bit such as coal miners use is often satisfactory, while in the sand a diamond-drill may be found most effective. Only a few hours are required for the drilling of each mine well.

Fig. 3 shows the method of drilling mine wells. In stratified sands, instead of enlarging a cavity in the bottom of the sand by reaming or shooting, the holes may be designed to penetrate the oil-bearing formation, or to reach any desired level therein.

Any system of oil expulsion which is operable from the surface of the ground, through hundreds of feet of earth strata, is bound to be much more effectively operable from mine tunnels where the mine wells are only a few feet in depth and cost possibly $100 each. At the beginning of the operation of a mine in any locality, it may be well to experiment with different expulsive agents (air, gas, and water) to

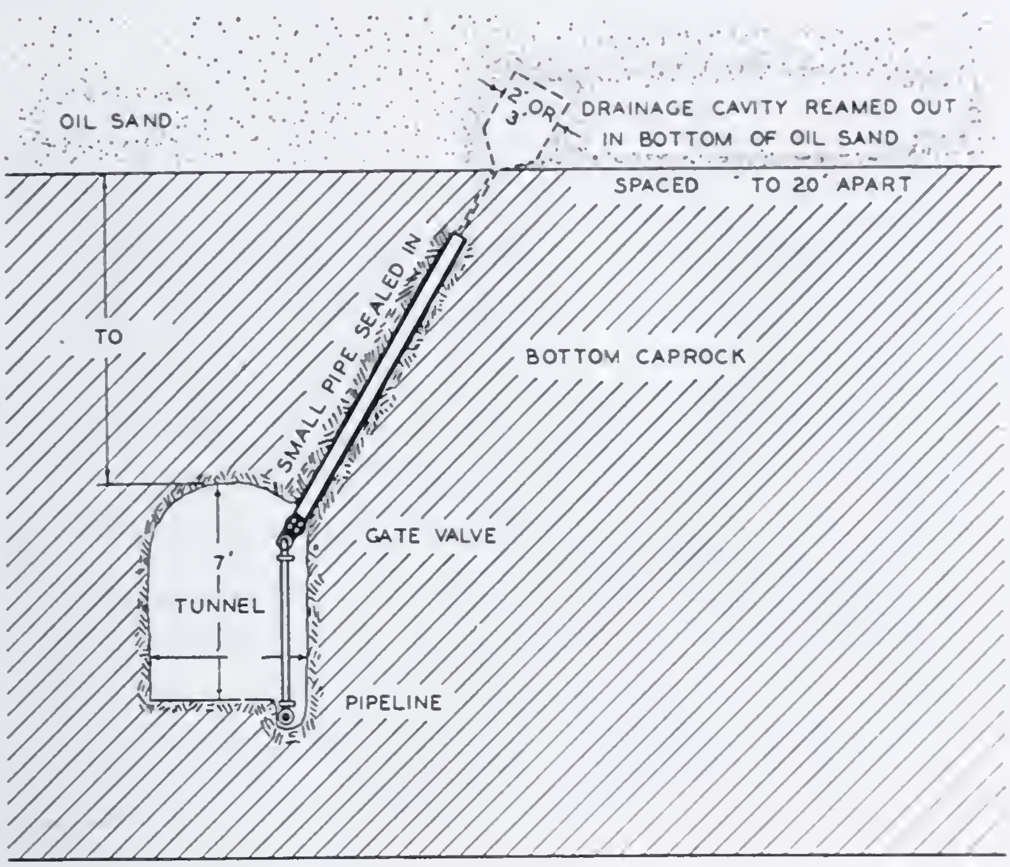

Fig. 3. Method of Enlarging Drainage Cavities.

determine which is economically the most effective in that field. Since water has proved itself the best expulsive agent in the Bradford field, it is assumed that in many fields the largest economic recovery may be by a water flood through mine wells. However, it must be borne in mind that neither the air drive nor the gas drive has been so scientifically developed as the present "five-spot" method.

Fig. 4 illustrates water flooding in an oil mine. Pressure tunnels alternate with producing tunnels so that oil is driven to the producing wells from both sides. Since the lines of flow of both the oil and the oil expellant are parallel, the rows of mine wells may be spaced two or three times as far apart as wells in a "five-spot" arrangement. Each producing well and each intake well is equipped with a valve to regulate the amount of fluid leaving or entering the well. When curtailment becomes necessary, pressure is reduced on the intake wells; and when an increase of production is desired the pressure on the intake wells is raised.

As shown in Fig. 5, when low pressures are used, it is feasible to apply different pressures to horizons of different permeability in oil-mining operations. Two different pressures are applied in the same mine well, but separate mine wells may be drilled to each hori-

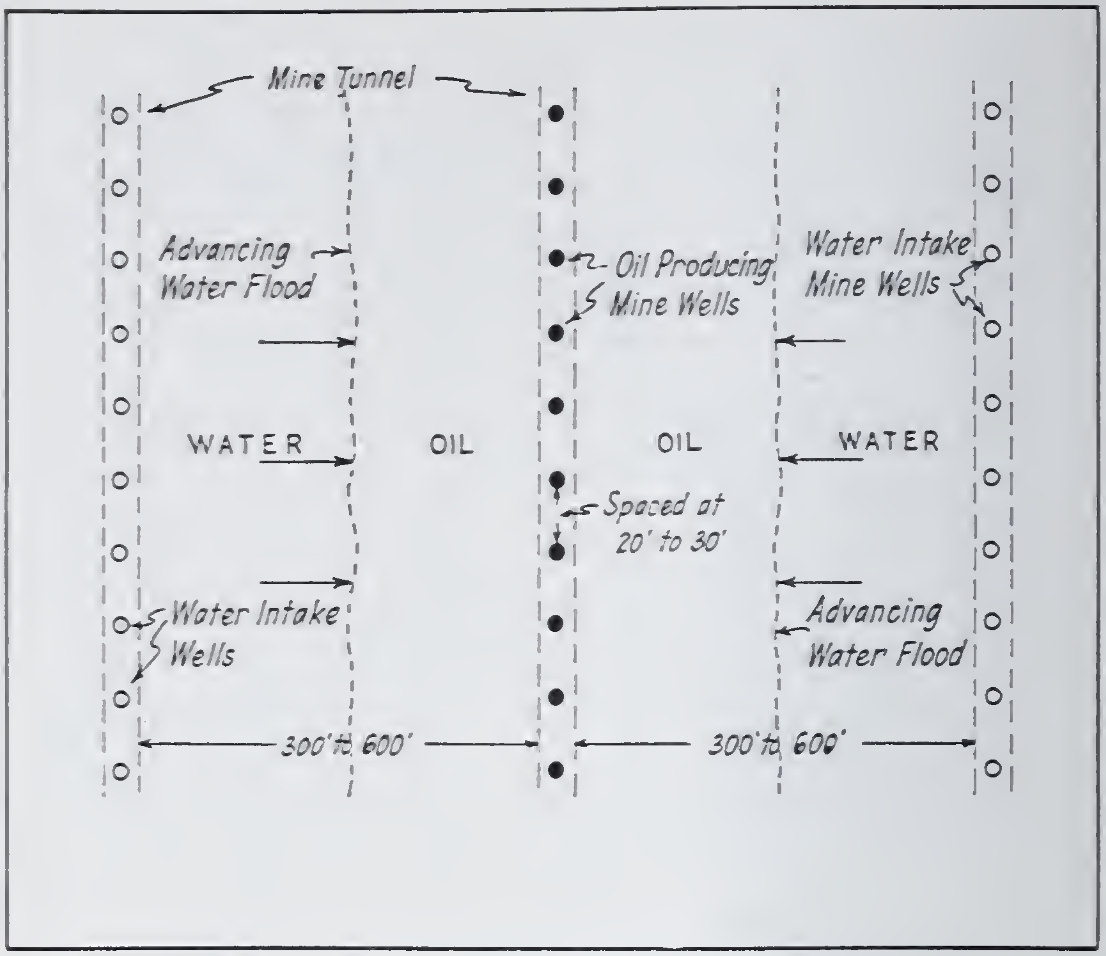

Fig. 4. Plan View of Water-Flooding Installation.

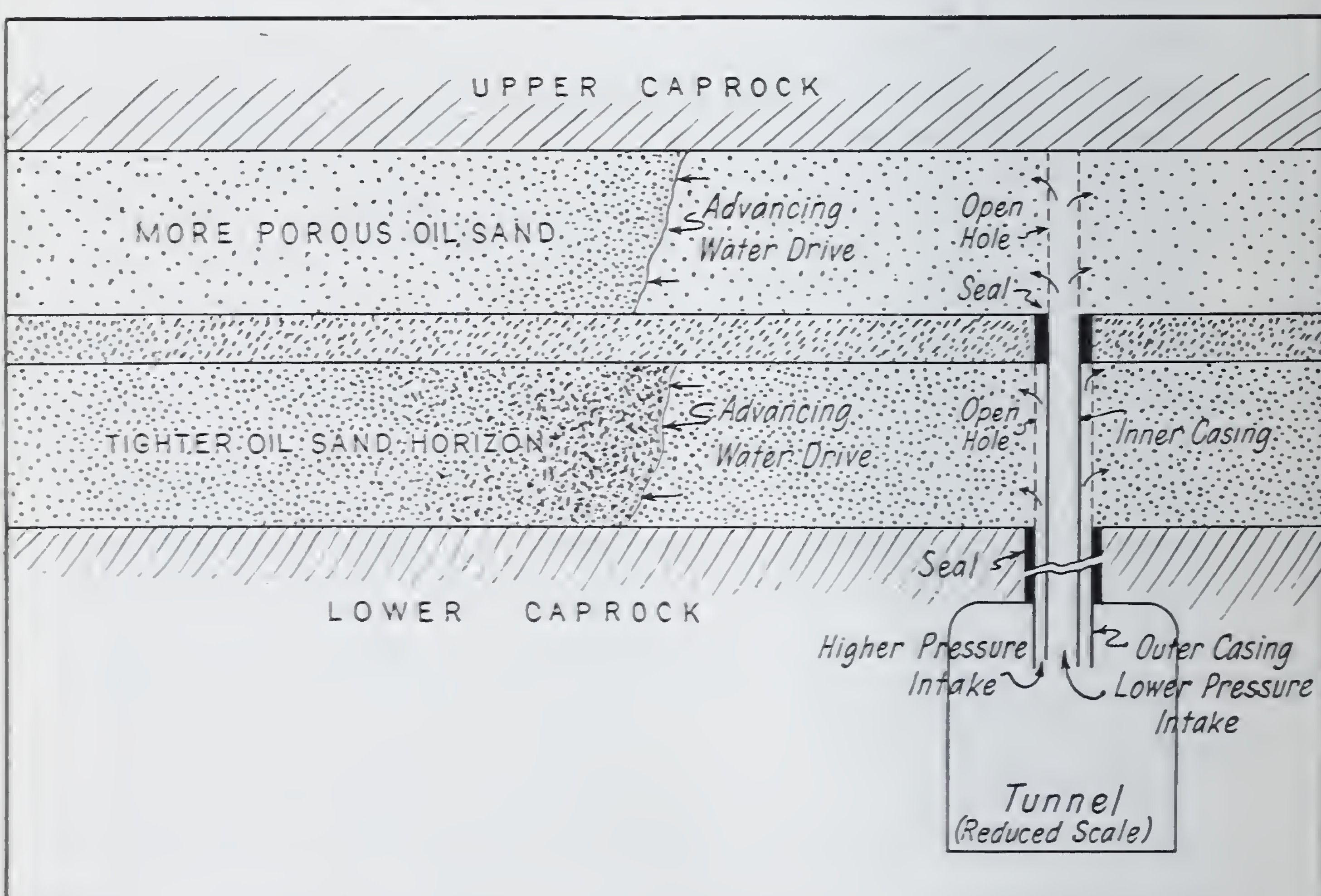

Fig. 5. Adapting Pressure to Permeability in Flooding through Mine Wells.

zon at a small cost, should this be found desirable. By means of test pipes sealed to various levels in the sand from cross-cut tunnels, the advance of the water flood (or gas or air drive) is noted, and samples of the mixtures are taken and analyzed. By ascertaining the percentage of voids in relation to thickness of each substratum, the quantity of oil expellant admitted to each substratum may be so regulated as to maintain the substantially straight front of the expelling fluid. In like manner back-pressure in producing wells may be held on any desired substratum when draining that substratum separately.

It may be found that water flooding can profitably be conducted by the use of a soda-ash solution as developed by Dr. Nutting, to remove the film of oil from sand grains. The principal difficulty in present methods of applying such solutions is that wells from the surface of the ground can not be economically drilled close enough together to enable the solution to be rejuvenated when it has lost its strength.

Professor Lester C. Uren has developed a method of rejuvenating these solutions when used in connection with oil-mining operations. This system comprises operating the oil sand in blocks, with tunnels driven below the sand on all four sides of each block. The tunnel on the lowest side of the block is equipped with pressure wells for the injection of solution, while the tunnel on the opposite, or highest side of the block, is equipped with producing mine wells. Just below each end of the block of sand is a cross-cut tunnel equipped with test pipes which will be described later, these test pipes being utilized to draw off samples of the advancing flood of solution. When samples indicate that the mixture is becoming weak, a cross current of fresh material is injected (just back of the oil-water interface) from one cross-cut tunnel to the one at the opposite end of the block, and thus a fresh flood is introduced just behind the oil. In this way the solution is kept fresh until all recoverable oil in the block has been expelled.

A possible application of soda-ash solution through mine wells is shown in Fig. 6. When it appears from sampling at the test holes that the solution is becoming weak, a cross current of fresh solution is established just back of the oil-water interface, and thereafter only water is introduced into the row of intake wells.

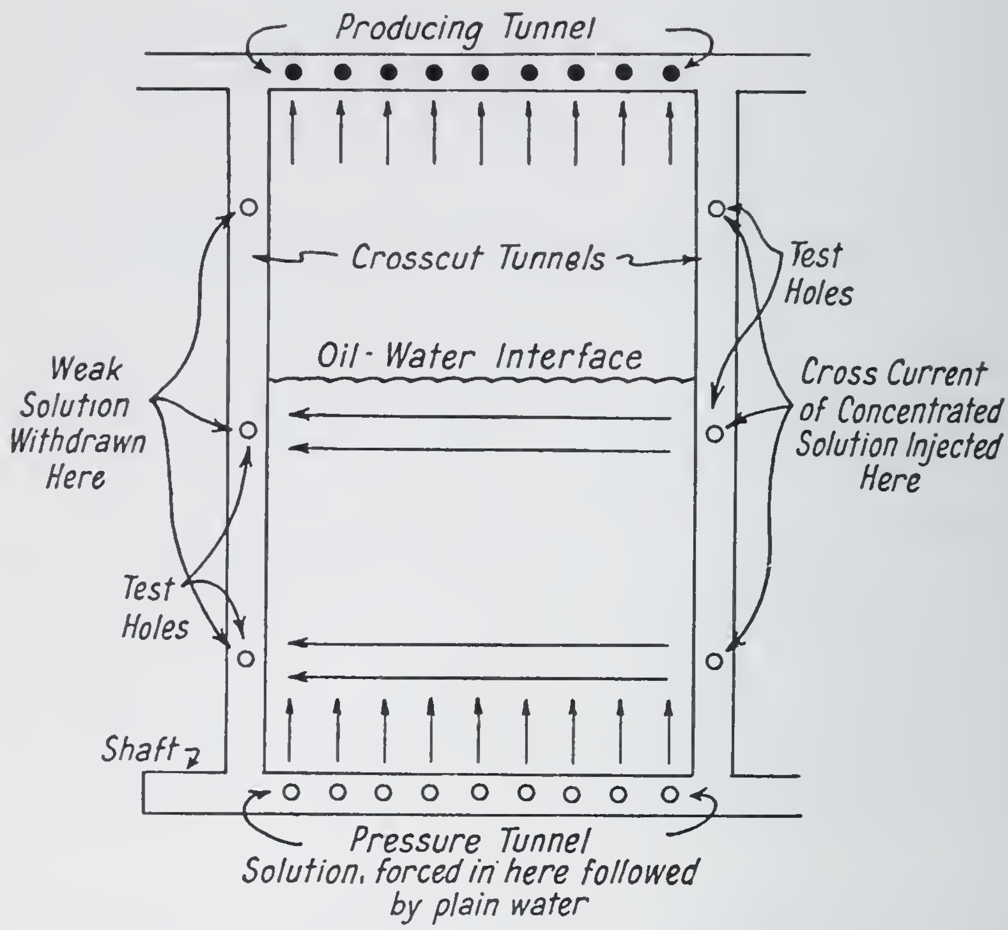

Fig. 6. Application of Soda-Ash.

In installing a water flood in an oil mine, a pipe is lowered into the shaft or through a well drilled to a tunnel, and the head of water in this pipe is utilized to flood the sand. Should the hydrostatic pressure be insufficient, a pressure pump is employed on top of the ground. The pipe delivering oil to the surface may extend up through the shaft or through a well drilled down to the workings. The actual cost of pumping the fluid to tanks above ground may be estimated from the expense of pumping water from metal mines and coal mines. In those cases it is found that the average cost at a depth of 500 feet is usually less than one cent per barrel of fluid elevated.

In "five-spot" operations water passes quickly through the most permeable level in the sand, driving the oil out of the permeable substratum and making it still more permeable to the water flood. Much of the oil in the less permeable substrata remains untouched, while the flood by-passes through the offending stratum. It is impracticable to drill separate wells to each horizon, and also impracticable to maintain different pressures in the same well at a depth of 1000 to 2000 feet. See Fig. 7.

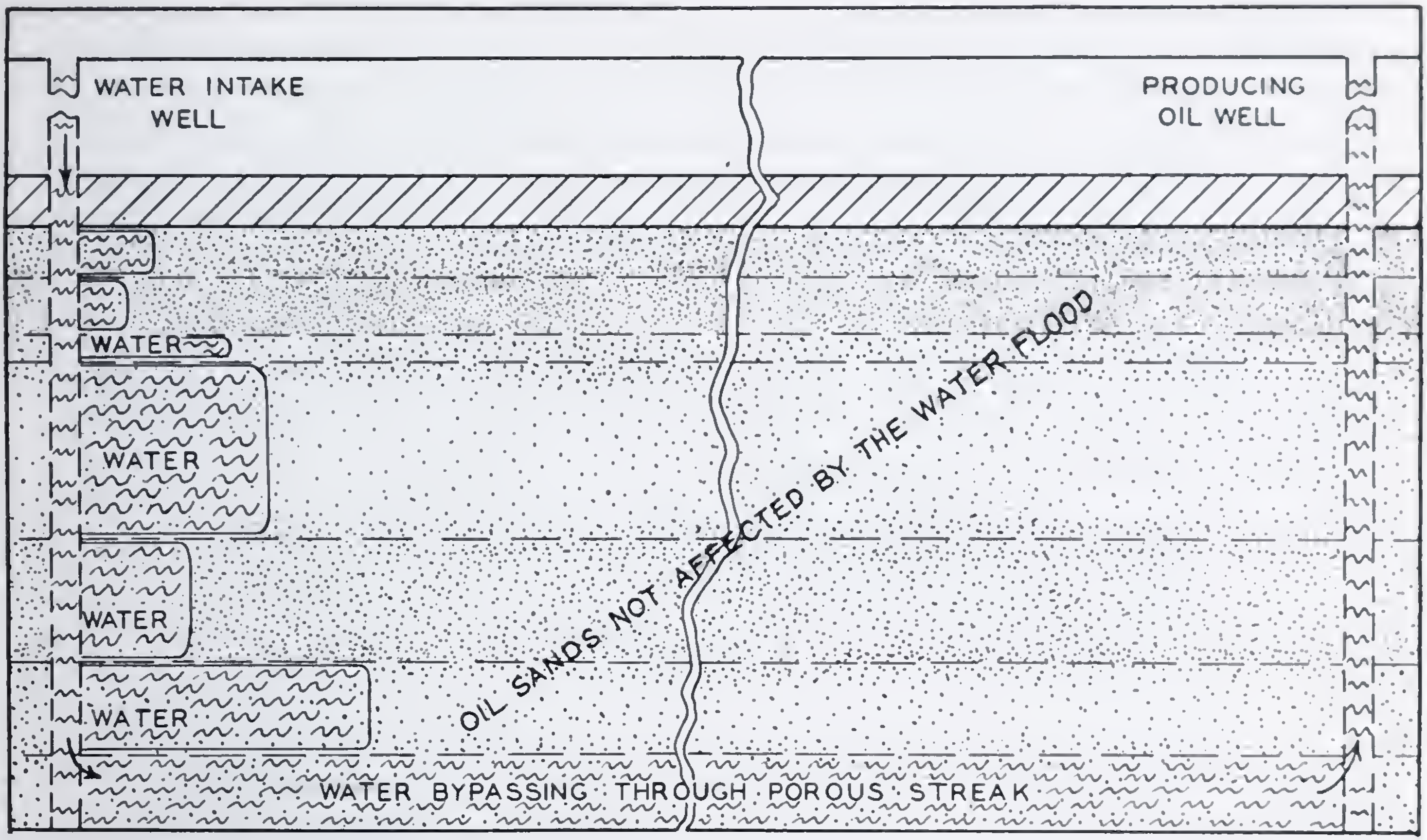

Fig. 7. Movement of a Water Flood through Oil Sands in Present Practice.

Ventilation. It is commonly assumed that the ventilation of an oil mine must necessarily constitute a serious problem. This assumption is based upon the fact that gas is associated with oil; that oil itself gives off explosive vapors; that the ventilation of gaseous coal-mines is difficult; and that years ago there were serious fires and explosions in the oil mines at Péchelbronn. All this has very little bearing upon the ventilation of oil mines installed under the Ranney process.

In the first place, no tunnels are driven in the oil sand, all of them being formed in impervious shale below (or above) the sand. Oil and gas are not allowed to enter the operating tunnels, which may have dry floors. All drilling in the oil sand is done through stuffing-boxes, and the oil and gas are confined at all times within pipes until delivered on top of the ground. Fissures occurring in the tunnel walls are sealed.

The ventilation of gaseous coal-mines is a problem because of worked-out areas, abandoned rooms, and pockets for the collection of gas. In oil-mining operations no such gas traps exist. All the workings are straight tunnels through which air is easily circulated. The explosions which were troublesome in the French oil mines happened

because at that time the galleries were driven within the oil sand, and oil and gas were allowed to issue from the walls, roofs, and floors of the tunnels. In the main this hazard no longer exists and it is reported that no fires have occurred in the French mines since a form of the process under discussion was adopted there.

Spacing of Tunnels. The distance between pressure tunnels and producing tunnels is governed by several factors, the most important of which are the following:

1. The permeability of the sand.
2. The viscosity of the oil.
3. The desired rate of oil extraction.

To estimate the proper spacing of tunnels, it is necessary to assume values for these variables. Let us assume, for instance, that the porosity of the sand is 13 to 18 per cent., the saturation 75 to 85 per cent., the gravity of the oil about 40 degrees, and the time of extraction for a given block being mined, five years.

It has been shown by mathematical calculation, and by experiments in the laboratory by Uren,* that, as lines of flow through a sand approach a parallel instead of a radial flow, the resistance offered by the sand decreases rapidly. Uren has shown that if the diameter of a producing well were 20 feet, the wells may be spaced 2½ times as far apart as when the diameter of the well is six inches, because the lines of flow are more nearly parallel. In producing oil by this system of mining, the lines of flow *are* parallel, therefore it may be assumed that pressure and producing tunnels may be spaced from two to three times as far apart as in the present "five-spot" operations at Bradford. If in a "five-spot" operation the water intake wells are spaced 300 feet apart, the distance from water well to producing well is approximately 210 feet. Therefore, in mining a sand such as the Bradford, if a water flood is employed, producing and pressure tunnels probably may be spaced from 400 to 600 feet apart. No higher pressures should be required in that instance than are required in the present Bradford operations.

Fig. 8 illustrates the horizontal "fingering out" of an oil expellant when applied from surface wells. This is impossible when pres-

***Trans. A. I. M. and M. E.*, v. 71, p. 1276.

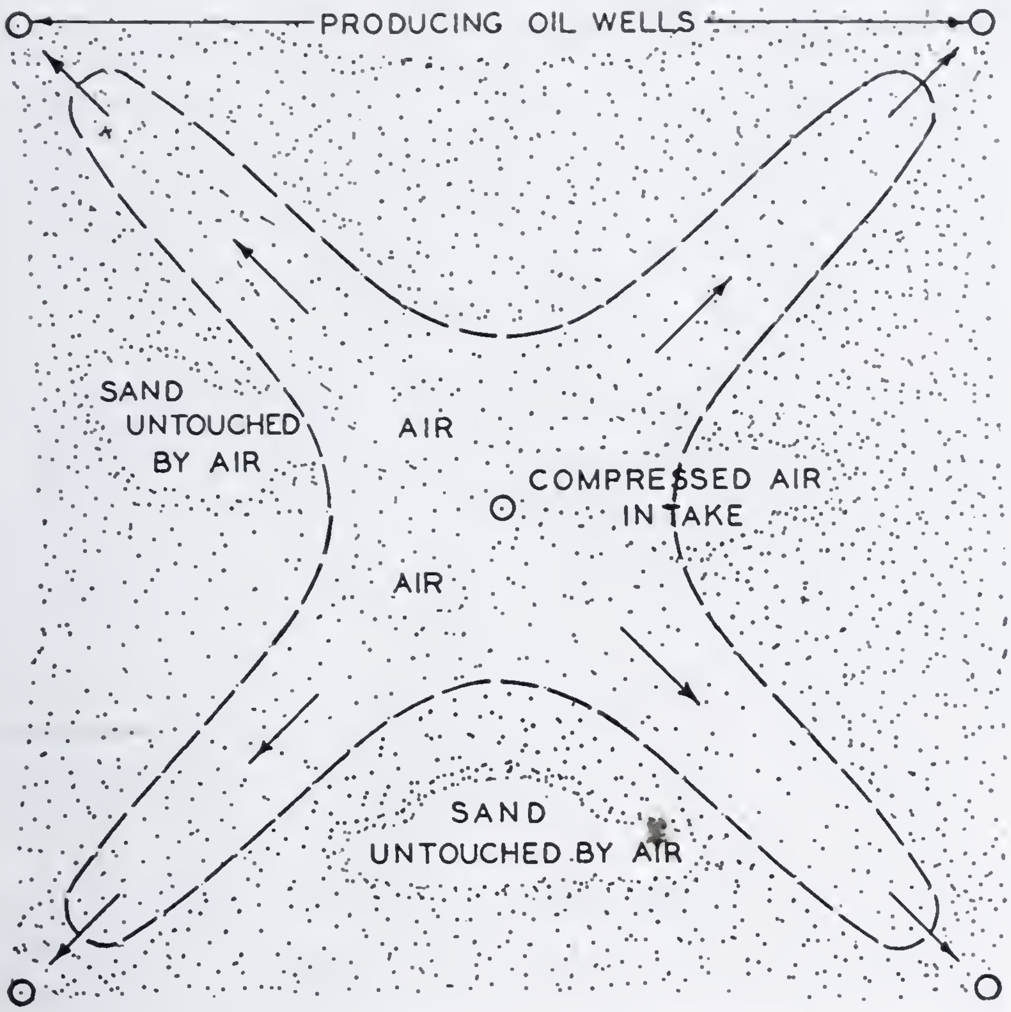

Fig. 8. Diagram of Air Drive.

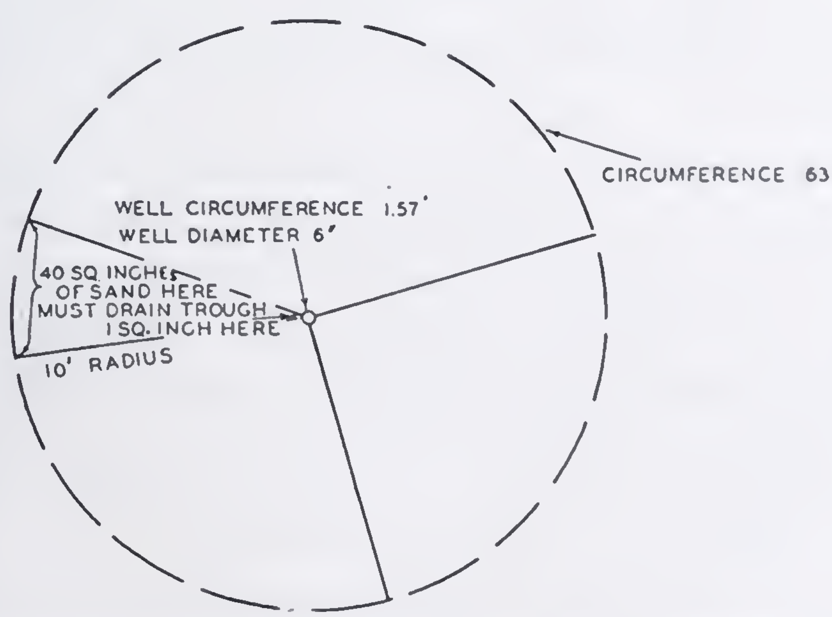

Fig. 9. Convergence of Lines of Flow toward Oil Wells.

sure wells are spaced 20 feet apart and the advancing wave of the expellant is a straight line as in mining.

Fig. 9 indicates the ineffectiveness of radial flow from or to wells drilled from the surface of the ground. In a producing well, resistance increases as the well is approached, while in a pressure well the pressure is dissipated as the oil expellant moves away from the intake. Both of these factors are eliminated when the lines of flow are parallel, as they are in oil-mining operations.

Percentage of Recovery Expected. Before flooding operations were instituted in the Bradford field, experienced operators doubted the possibility of secondary recovery, by any new method, approaching the past production of that prolific area. Before demonstration of the water flood, successful users of the air drive had assumed that they had reached the ultimate in methods of oil extraction; and to-day it is probable that the operators who believe the "five spot" to be the last word in oil recovery are as far wrong as the former operators who scoffed at the water-flooding idea.

It can not be doubted that in the ordinary application of an air drive or a water flood in eastern fields, a large percentage of the oil in the rock is by-passed. Water or air forced into an oil sand is bound to follow the path of least resistance, and this path is bound to be through the most permeable streak in the sand, in a relatively narrow strip toward an outlet. This narrow strip in the permeable substratum is rapidly denuded of oil, and the more rapidly the oil is removed the more permeable the streak becomes until the repressuring agent has established a channel through a strip of sand direct to the producing well. From that time on, unless the pressure is greatly increased, the well tends to produce only the repressuring agent to the exclusion of oil. Increased pressure, back-pressure and delayed drilling are successful to only a small degree in overcoming this tendency. It is possible to eliminate this obstacle only by applying different pressures according to different permeabilities in substrata, and by maintaining a straight front horizontally on the advancing body of the expelling agent. These two things are believed to be accomplished in the method of mining under discussion.

From core analyses some years ago, Melcher* estimated the average recovery in eastern fields at approximately 10 per cent. of the

**Oil and Gas Journal,* v. 23, May 5, 1925, p. 144.

original oil content. I believe he still adheres to this estimate, although some operators place the recovery by natural methods as high as 20 per cent.

In no case have I heard of air repressuring in which secondary recovery has been as much as one-half of the previous recovery by natural methods, though such cases may exist. Recovery by water flooding in the Bradford field is believed by various operators to be from 12 to 25 per cent. of the original oil content. It may be assumed, therefore, in the Bradford field, that total recovery to date ranges between 20 and 30 per cent., and in exceptional cases is as high as 40 per cent. of the original oil. In other words, when flooding operations have been completed, between 60 and 80 per cent. of the oil is still left in the sand. When an air drive becomes uneconomic, probably from 75 to 85 per cent. of the oil remains in the ground.

Reports on the mining operations at Péchelbronn are to the effect that by the use of a modification of the process here outlined approximately 65 per cent. of the oil remaining in the sand has been recovered, in spite of the fact that repressuring by air has been limited to the application of pressure in alternating mine wells, and the production of oil from intervening wells, in the same tunnel. A drive from one tunnel to another has not to our knowledge been attempted, nor has the application of a water flood. In consideration of all these things, there seems justification for the belief that oil mining scientifically applied in the majority of the Appalachian fields will recover from 65 to 75 per cent. of the oil remaining in the sand. If a soda-ash solution be employed, the upper limit might be raised to 85 per cent.

Time Required for Extraction of Recoverable Oil. The most satisfactory period in which secondary methods of recovery are in operation on a given area being worked depends upon the price of oil and the cost of recovery. If oil commands a high price, operators feel justified in hastening recovery by spending larger sums on more intensive development. In the Bradford field, to be able by the "five-spot" method to recover the extractable oil in two years would require a much larger investment than to recover the same oil in five years. Likewise, to produce the recoverable oil in a block of sand in two years would require a closer spacing of tunnels than would be necessary for the five-year period. I believe the Bradford operators now

feel that, considering the initial investment, the price of oil, and the cost of development and operation, a period of four or five years from the time the flood is first applied until the wells are abandoned is most satisfactory.

In mining oil from a stratum of the average permeability of the eastern sands, the spacing of tunnels suggested above provides for the total extraction of economically recoverable oil in from four to five years. However, should a more rapid extraction be desired, the tunnels may be spaced more closely, or the pressure increased in the pressure lines.

A particular advantage in mining oil lies in the flexibility of the system. In mining operations it is proposed to have about 2.6 pressure wells and 2.6 producing wells for each acre of ground. Therefore, it is evident that should the time arrive during the life of a mine when a much higher rate of production is desired, with more than twice the number of producing and pressure wells employed in present flooding operations, any increase in pressure will be more effective in increasing the daily output. The potential production of an oil mine depends in large measure upon the pressures applied, and a mine on an oil property tends to transform the oil sand into an underground storage reservoir from which the oil may be recovered slowly or rapidly. In the present plan it is contemplated that the period of extraction on a given block of sand will be five years from the time the tunnels are driven. A good mine fully developed on 1000 acres should have a daily average production of 5000 barrels.

Cost of Mining Oil. Assuming sand at a depth of 500 feet; land at a cost of $200 an acre; a system of producing tunnels spaced 400 feet apart; and a system of cross-cuts spaced at 800 feet, the cost of an installation on 1000 acres is tentatively estimated as follows:

Two shafts, 500 feet deep	$ 125,000
Producing and pressure tunnels	1,156,000
Extras, main haulage, etc.	136,000
Nine cross-cut tunnels	576,000
Shaft bottoms, doors, undercasts, regulators, brattices, etc.	128,000
Test-pipe installations (500)	40,000
Mine wells (6000)	600,000

Equipment	300,000
Core analyses	40,000
Supervision	40,000
Cost of installation	$3,141,000
Cost of land	200,000
	$3,341,000
Contingencies and extras	259,000
Grand total	$3,600,000
Cost per acre	3,600

Actual money required to put the mine on a basis so that profits will finance extensions should be from $600,000 to $700,000.

Several fields now under consideration have an indicated oil content of 20,000 to 30,000 barrels per acre. While a recovery of more than 65 per cent. is expected, the recovery per acre will be 12,000 barrels if only 60 per cent. of the smaller amount is extracted. The possible economics of the installation may be estimated as follows:

Amortization to return capital advanced. (A duplication of six cents of the item of 30 cents a barrel, below)	$ 720 per acre	
Interest on investment	540 per acre	
Overhead	360 per acre	
	$1620 per acre, or	13½ cents per barrel
Lifting cost and royalty		6 cents per barrel
Repressuring cost		14½ cents per barrel
Land, installation, and contingencies		30 cents per barrel
Total cost		64 cents per barrel

At a selling price of $2, the profit would be $1.36 per barrel, or $16,320 per acre. Should the recovery be only 8000 barrels per acre,

the net profit would be reduced to $9000. One installation should suffice for 1000 to 3000 acres, depending upon the depth to the sand.

Conclusions. It appears that for years to come there will be a slowly growing demand for oil of Pennsylvania grade, provided the same grade of lubricants can not be made from other crudes at a lower cost.

The selling price of Pennsylvania oil will be governed by the cost of making an equal grade of motor oil from other crudes, but it seems reasonable to expect a market value of about $2 a barrel.

There is every reason to believe that oil mining, having been demonstrated and used elsewhere, should be successful in eastern fields and should recover a much higher percentage of residual oil than the secondary methods now in use.

Production of this oil by mining promises greater flexibility than by present methods.

The cost per barrel of mining oil from the eastern fields is indicated as much below present costs of secondary recovery.

A substantial profit per acre is anticipated from mining operations in the Appalachian oil-fields.

DISCUSSION

W. D. Barrington:* Having previously read two articles on the possibilities of oil mining in the Appalachian fields, my interest in the subject was aroused by a preprint of Mr. Ranney's informative and valuable paper.

The possibilities revealed seemed to demand more than passive attention, and particular interest was created in the method of development to the point of drilling the pressure and producing wells, test holes and repressuring system, due to the apparent similarity in the partial development of coal properties. Therefore, a preliminary mining and ventilating plan for the Ranney oil-mining system was prepared as shown in Fig. 10, using the double-entry system of mining, and from this plan certain mining and ventilating requirements and cost estimates were calculated.

*Research Engineer, Consolidation Coal Co., New York.

Although Mr. Ranney does not expect gas and water problems or trouble from the roof, it was thought best, for safety precautions to prepare for these, and to meet legal requirements, to assume a "gaseous" development and then make further calculations on two "non-gaseous" developments, if allowable, with the pressure and oil producing headings driven, first, 600 feet from center to center and entries 800 feet from center to center; and, second, driven 400 feet from center to center and entries 800 feet from center to center, using the single-entry system (with blowers and tubing for ventila-

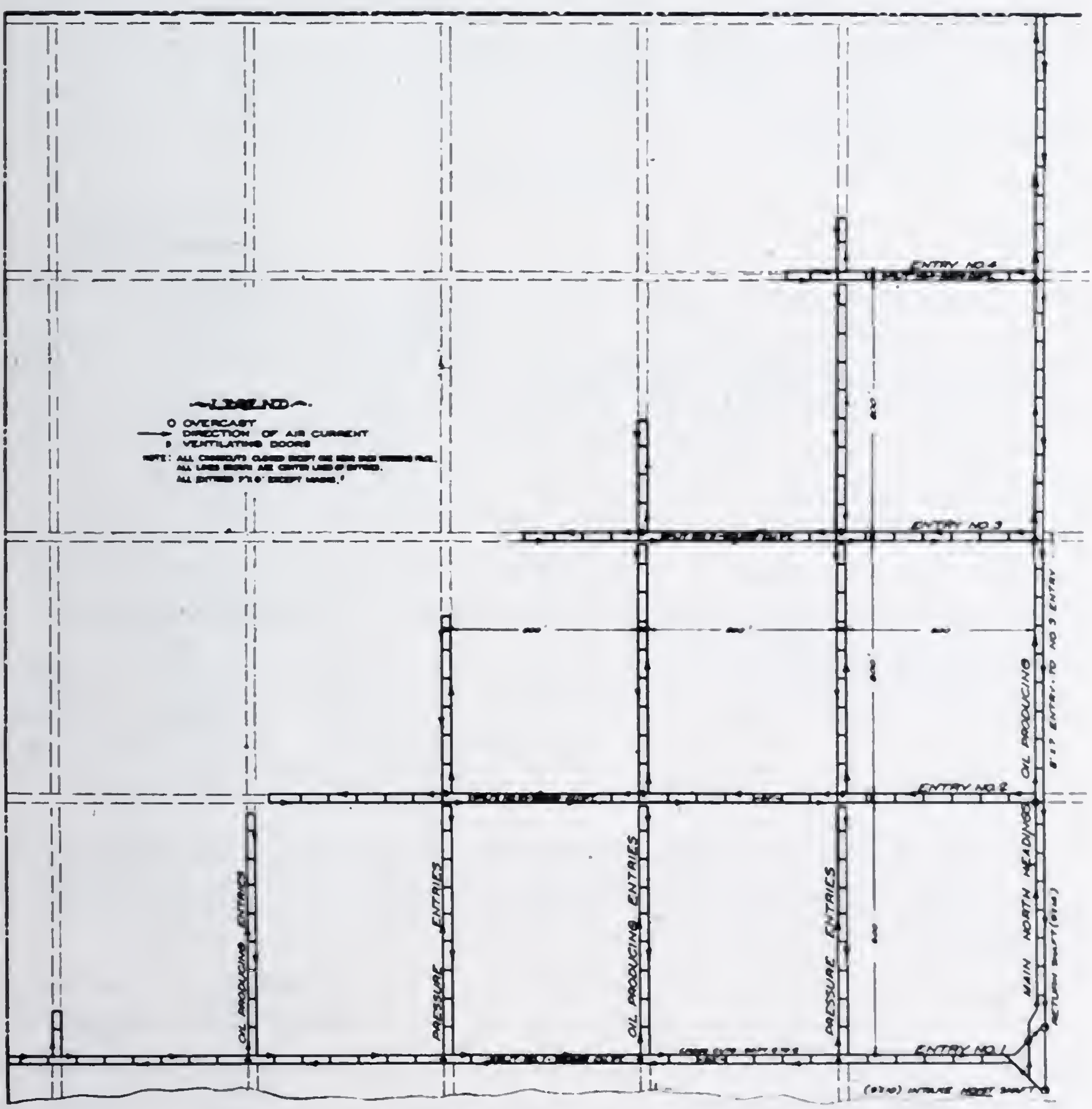

Fig. 10. Preliminary Plan for Ranney System.

tion) on all headings and entries, although maintaining double entries for the mains. The non-gaseous methods of operation when adopted would naturally reduce excavation costs.

The excavation estimates for entries, pressure and producing headings and cross-cuts under the three systems of development as previously mentioned are as follows:

1. Gaseous.
2. Non-gaseous; headings 400 feet from center to center.
3. Non-gaseous; headings 600 feet from center to center.

In a gaseous development we have anticipated a progress in driving of about 36 lineal feet a day minimum, and about 324 feet maximum, with an average of 180 feet working three shifts. Under this progress about 7½ years would be required to develop the 1000-acre tract completely, though conditions may be such that development could be more rapid.

Development

		Non-gaseous	
	Gaseous	400 feet between centers	600 feet between centers
Entries (six by seven feet), lineal feet	253,200	162,000	136,400
Entries (seven by eight feet), lineal feet	6,800	6,800	6,800
Cross-cuts	26,610	2,600	2,600
Total lineal feet	286,610	171,400	145,800

Cost

	Gaseous	400 feet	600 feet
Entries (six by seven feet) at $10 a foot	$2,532,000	$1,620,000	$1,364,000
Entries (seven by eight feet) at $13.50 a foot	92,000	92,000	92,000
Cross-cuts at $5 a foot	133,000	13,000	13,000
Total	$2,757,000	$1,725,000	$1,469,000

The timber-lined shafts, 500 feet deep, constructed for the requirements of the gaseous development showed an estimated cost as follows:

	Hoist shaft 9 by 10 feet	Air shaft 9 by 14 feet
Excavation, cubic yards	1750	2333
Excavation at $9.20 a yard	$16,100	$21,470
Shaft collar 50 feet deep	3,100	4,000
Grouting and ceiling at $10 a foot	5,000	5,000
Water at $5 a foot	2,500	2,500
Guides at $150 a thousand board feet	600	....
Timbering at $100 a thousand board feet	4,200	5,300

Wood lining at $75 a thousand board feet	2,260	2,860
Sump	500	610
	$34,260	$41,740

Total	$76,000
Engineering and contingencies	8,000
Grand total (two shafts)	$84,000

The gaseous development, as shown in Fig. 10, requires provision for overcasts, regulators, stoppings and doors which we estimate would cost about as follows:

Required overcasts, 16 at $600 each	$ 9,600
Emergency overcasts, four at $600 each	2,400
Regulators and stoppings, 1500 at $10 each	15,000
Doors, 20 at $20 each	400
Total	$27,400

For the main auxiliary equipment such as fan, substation, hoist and skip, head-frame and buildings, we estimate $150,000. Added to the previous items of $2,757,000, $84,000, and $27,400, this gives a total of $3,018,400 for the gaseous development.

The ventilation problem, in the speaker's opinion, is of prime importance and therefore some calculations on this feature were hurriedly prepared covering the double-entry system for the gaseous development using the ventilation arrangement and air quantities as shown in Fig. 10. Some of you gentlemen will probably be interested in the results of this work pertaining to total air volumes, water-gages, and power costs for ventilation.

In a gaseous development a volume of 160,000 cubic feet of air per minute was determined as the maximum for simultaneously developing two of the quarter sections of the 1000-acre tract. With storage motor operation permitting 0.5 per cent. gas maximum on the return, this quantity of air would remove approximately 1,152,000 cubic feet a day. We believe the amount of air stated previously would be sufficient to develop the entire tract of 1000 acres; that is, if two diagonal quarter sections were developed first, the remaining sections would be opened on two sides and probably would not require as much air as those developed first. The original sections being worked out, the volume of air required for them would be diverted to the active or developing quarter sections. Such theory is

subject to change due to unknown conditions as regards quantity and nature of gas to be encountered, action of ventilating current of air on the shale, etc. Based on requirements of 160,000 cubic feet of air per minute, maximum, the daily power cost for ventilation for various air volumes was figured from the following factors and the layout as shown in Fig. 10:

Water-gage in inches	
Maximum split, No. 1 entry	5.5
Air shaft return	1.17
Air shaft intake	1.17
Total	7.84

Cost of fan operation	
Power cost per kilowatt	$0.01
Fan efficiency at	70 per cent.
Motor efficiency at	90 per cent.
Belt efficiency at	95 per cent.
Overall efficiency at	60 per cent.
Calculated air horse-power	198
Calculated required horse-power	330
Calculated daily power cost	$59.08

Air volume per minute	Daily cost
160,000	$59.08
140,000	39.58
120,000	24.92
100,000	14.42

In conclusion, it seems advisable to state that with a selected site for development, known facts regarding conditions under which the oil mining would proceed, and the customary survey with time for proper study, one probably would be able to predict costs more accurately than shown in these hurriedly prepared preliminary estimates, and therefore the speaker requests his listeners to keep this feature in mind when analyzing the figures presented.

One will note, however, that under the more expensive gaseous system of development as presented herewith, from a mining development standpoint, Mr. Ranney's method indicates a substantial profit, and under the non-gaseous development considerable conservatism in the estimated cost of mining is displayed by Mr. Ranney.

In the estimate of 7½ years for complete development, under gaseous conditions, of the 1000-acre tract, only two shafts would be

sunk of the sizes specified. If the development were non-gaseous this time could be reduced. If necessary to speed development, larger size shafts could be used or additional shafts constructed.

W. J. Brundred:* In connection with mine ventilation, would it require a greater circulation of air for gas at 2000 B.t.u. than with gas of a nature commonly encountered in coal-mines?

W. D. Barrington: I am not familiar with gas of that type (2000 B.t.u.) in coal-mines. Our experience is with methane around 1000 B.t.u. per cubic foot and in one instance natural gas of about 1200 B.t.u. per cubic foot. The natural gas we encountered in West Virginia was 1150 B.t.u. per cubic foot and consisted of methane and ethane in ratio of 85 per cent. to 15 per cent., respectively, with a little nitrogen.

C. H. Dorsey:† What is the average thickness of the oil sands?

Leo Ranney: It depends on the field. In the Bradford field it is about 30 feet.

G. S. Rice:‡ What is the estimated average cost of drilling the upward drainage holes under the conditions you have cited, per foot of length or per drill hole of an assumed average length?

Leo Ranney: The cost should not be over $100 per mine well. If there are 20 feet of shale between the tunnel and the sand, each mine well might penetrate 25 feet of shale and the casing might be grouted in for a length of 20 to 24 feet.

C. H. Dorsey: Does that include the grouting in of the pipe?

Leo Ranney: Yes.

C. H. Dorsey: Would the water pressure be less in the 25-foot spotting than the 300-foot spotting?

Leo Ranney: We do not contemplate putting the mine wells 300 feet apart.

*President, Brundred Oil Corporation, Oil City, Pa.
†Treasurer, R. G. Johnson Co., Pittsburgh.
‡Chief Mining Engineer, United States Bureau of Mines, Washington, D. C.

G. W. Noble:* How will the tendency to by-pass be overcome in the new mining installation?

Leo Ranney: To overcome the tendency of the repressuring medium to finger out we build up a bank of repressuring medium. This is possible because the mine wells are so close together and under individual control, both in the pressure row and the producing row.

G. W. Noble: In Melcher's experiments at Coffeyville, Kansas, a well spacing of about 70 feet was used. The by-passing and fingering were in some cases more pronounced than in your sketch.

Leo Ranney: How did you establish the fact that there was by-passing?

G. W. Noble: The wells were arranged usually 100 feet apart in rows about 50 feet apart, with wells in alternate rows staggered in position with reference to adjacent rows of wells. Thus, though the wells in any one row were about 100 feet apart, the nearest wells in adjacent rows were only about 70 feet away. The line pressure drives had about 500-foot fronts. All pressure and producing wells were equipped with pressure-gages and pressures read daily.

Leo Ranney: As I recall and understand Dr. Melcher's experiments, channels had already been established, so you would expect the repressuring medium to follow these channels. How far apart were the lines of producing and pressure wells? I have forgotten.

G. W. Noble: Five wells in line was the maximum.

Leo Ranney: Five closely spaced wells do not constitute a line long enough to be in any way similar to a line that might stretch out indefinitely as in an oil mine. A line of five wells is not long enough to enable the operator to build up a solid bank of the repressuring medium.

G. W. Noble: It was a completely inclosed pool, but was only about ten acres in size.

*District Superintendent, Midland Natural Gas Co., Clarksburg, W. Va.

LEO RANNEY: That is the same thing. It is accounted for by the fact that the channels were already established and the repressuring agent simply followed the old channels, neither the pressure nor the producing wells being under accurate control.

G. W. NOBLE: Two wells had been drilled in the immediate area several years before. They were equipped and handled exactly as the wells drilled during the experiment.

LEO RANNEY: How far were the producing wells from the pressure wells?

G. W. NOBLE: Well spacing was about 70 to 140 feet, but in a few cases wells were drilled as close together as five feet. When the work was started there was no pressure on the sand. Air and natural gas were used in different parts of the pool.

LEO RANNEY: A spacing of 70 feet between pressure and producing wells seems too close for field-size experiments to determine the point in question.

G. W. NOBLE: Oil was permitted to flow from the producing wells as rapidly as it would accumulate, but the producing wells were allowed to remain open only while they were actually flowing oil; they were kept shut in whenever they would blow gas through with the oil. However, the drive did not move forward carrying all the oil ahead of it. In many cases there were seven or eight rows of wells producing at the same time. The producing wells completely surrounded all pressure wells for a considerable distance, at the ends of the lines of pressure wells as well as in front of the lines.

LEO RANNEY: I do not recall the finer details of the experiment definitely enough to discuss it fully with you, but I do think that Dr. Melcher believes we can accomplish what we propose to do.

G. W. NOBLE: Closer drilling can build up pressures more rapidly, but can not of itself overcome the tendency to by-pass.

LEO RANNEY: Dr. Melcher could not do things that we propose, because we shall work right at the sand with gate-valves to

control the intakes. If a well takes too much water or gas or air we simply turn down the valves.

G. W. Noble: Uniform volume to each pressure well would prove more effective than trying to maintain uniform pressure on each pressure well.

T. B. Sturges:* In making your holes up into the sand, you are working through a stuffing-box. How do you take off your cuttings?

Leo Ranney: The cuttings come out with the oil, before and after the drill is removed, through a tee in the pipe just above the stuffing-box, but none of that oil or gas escapes into the tunnel.

T. B. Sturges: You could take it from some sump where you direct the oil and gas.

Leo Ranney: Yes.

T. B. Sturges: You speak of drilling 50-foot holes by machines at the start with the possibility of reaming them out. I can not figure how you can do it except in very exceptional circumstances. Our oil sediments here are harder than the ordinary Texas sands and $2 seems too low for the cost of drilling.

Leo Ranney: This was not made on Bradford sand, but on another that was not quite so hard as the Bradford sand.

K. C. Heald:† Our cost is 65 cents, which includes the figure for amortization. Drilling in a tunnel or shaft will be more expensive. It still seems as though it should be possible to drill for about one dollar. These figures are on about 100,000 feet of drilling.

L. E. Young:‡ When the invitation was extended to me to take part in this discussion it was suggested that possibly as a coal operator there would occur to me various objections to the proposed

*President, Pennsylvania Drilling Co., Pittsburgh.
†Geologist, Gulf Oil Companies, Pittsburgh.
‡Vice-President, Pittsburgh Coal Co., Pittsburgh.

method of mining as related to coal-mining operations at lesser depths. After careful consideration there does not occur to me any good reason for raising objections; it seems to me that all the difficulties can be overcome by good engineering practice.

From an operating standpoint it is interesting to visualize the type of operation that Mr. Ranney proposes. It fascinates a coal producer whose plans from day to day are subject to rapid changes due to the orders of a sales department, to think about a mining operation in which there can be such definite scheduling of driving of entries, drilling, etc. By the proposed methods, production can be increased or reduced daily to meet the market requirements. The problems of rock pressure, gas pressure, and water pressure impress me as being very important. Ventilation apparently will present the greatest difficulties, but with closed lights and compressed air it ought to be possible to carry on operations under the most difficult conditions we can imagine.

In the financial set-up proposed, a tract of 1000 acres was assigned to one operation. Undoubtedly for greater depths a larger tract would be made tributary to the shafts, and the capital requirements would not be increased per barrel of recovery.

As a whole, the proposed plan presents a great many interesting features and problems. From an engineering standpoint these problems can be solved. The economics of the oil industry apparently will determine the feasibility of the project.

J. French Robinson, *Chairman:** Mr. Rice, may we hear from you?

G. S. Rice: Mr. Ranney's interesting paper and the subsequent discussion contained many suggestive points. Mining for oil is a problem that I have studied for the past eight years as some of those present are aware from a paper given in 1925 before the American Institute of Mining and Metallurgical Engineers,† and from an informal talk which I gave before this Society two years ago.‡ Since then I have again studied the problem in the only mines of size now in existence at Péchelbronn, France, and Wietze, Germany, and at

*Geologist and Engineer, Peoples Natural Gas Co., Pittsburgh.
‡*Trans A. I. M. and M. E.*, 1926, v. 74, p. 857.
‡Unpublished.

the present time I am preparing an extended report for publication by the United States Bureau of Mines.

One of my tentative conclusions is that there is a greater gain from mining depleted oil sands, in possible returns per unit area of sands, with depth of sand, over the present method of drilling closely spaced wells for repressuring until a limiting depth is reached where temperatures and pressures would be too great for mining. This limiting depth I would tentatively set at 4000 feet from the surface. It is true that in the gold-mines of the Rand, in South Africa, they have reached a depth in one mine of over 7500 feet; and in gold-mines in India and St. John del Rey (Morro Velho), Brazil, they have reached depths of over 6500 feet; also a Michigan copper mine has attained 5700 feet in depth, but all these mines are working in geologic formations with very strong rocks and with quite low ground-temperature gradients. In the case of coal-mines with softer formation and much higher ground-temperature gradients, there are some mines working in France, Belgium, and Germany, and one or two in Great Britain, which have reached a depth of about 4000 feet, but this depth is approaching the economic limit even under European labor conditions.

In petroleum fields recent temperature investigations have indicated that the ground-temperature gradient is high, probably higher on the average than in coal measures and the interbedded shale beds in which it is proposed that the mine tunneling be done would tend to flow under high pressure of the strata.

Most mines have a humid atmosphere, and the final controlling limit in mining is when the atmosphere in which the men work reaches (in saturated air) blood temperature. I would not, however, suggest attempting any preliminary extensive trial of petroleum mining methods in this country at great depth; in fact, it would be unwise to try it out at any depth of more than 1000 feet, and under the most favorable conditions that can be found while experience is being gained. Without reference to the comparative richness or poverty of the oil sands, I do not think that we can expect to find the favorable mining conditions of Péchelbronn or the favorable conditions as regards safety at either Péchelbronn or Wietze as concerns an oil free from gas and lighter volatile constituents.

As concerns the character of the shafts that have been proposed for reaching to or through the oil sand, I believe that from the standpoint of ventilation it would be much safer to have larger shafts than those indicated in Mr. Ranney's plan and in the discussion which followed. From a safety point of view it would also seem advisable that the shafts should be made with non-combustible linings, while to prevent leakage of gas and water it would be very desirable to use circular or elliptical shafts lined with concrete rather than rectangular wooden shafts, which, according to my experience, can not be made tight against water and gas under high pressure, even though cementation is tried. Moreover, if the successive oil-sand beds are to be passed through, it will be very important to have the shafts tight, especially if a system of water or gas drive of oil in the sands is employed, as proposed by Mr. Ranney and which seems to be vital in obtaining success for the plan of mining.

I am further convinced, from my studies of the problem, that ventilation is a vital factor, and that a more liberal allowance must be made than for a gassy coal-mine. In a trial of a new method with large initial investment you can not take chances of having an explosion or a fire disaster.

While the plans suggested by Mr. Ranney and his associates contemplate a thoroughly tight stratum of shale between the tunnels and the oil sand, supplemented if necessary by cementation, mining experience goes to show that there will inevitably be lines of weakness, faults, and fissures. While some of these may be sealed by forcing in cement grouting, it is quite possible, even probable, that they will be encountered unexpectedly, while in some cases it will be very difficult, if not impossible, to seal such fissures completely. Further, there is danger if a flaw occurs in a pipe-line or joint or valve, and finally the human element in mining hazards. All mining men know that at times some careless or unaccountable action of an individual leads to disaster.

J. French Robinson, *Chairman:* Following Mr. Rice's suggestion I might say that we have in the Appalachian field seven or eight well known producing oil horizons coming one under the other. I presume he had in mind starting a plan to work in the shallow seams and then go on down to the next ones. I see no reason why it could not be done.

W. J. BRUNDRED: Would it not be possible to work with one shaft and carry forward as the tunnel is driven some kind of ventilating tube, say a 12-inch pipe, and let the return ventilation go out the hoist shaft, or is it necessary to have a double shaft for this purpose? I had in mind the use of this method to reduce the cost of demonstration rather than the continued use of it if work on that specific property proved practical.

J. FRENCH ROBINSON, *Chairman:* Mr. Paul may be able to answer that question.

J. W. PAUL:* I do not know that I can answer it satisfactorily, but I am under the impression that when oil mining becomes a practice, the state legislatures will enact laws similar to the laws covering ventilation of bituminous mines and that would involve the use of two shafts. For experimental purposes, I presume some temporary ventilation might be used. For large tracts, I anticipate a need for ventilation similar to that used for bituminous coal-mines.

LEO RANNEY: As to the figure of 7½ years, of course with larger shafts you could speed up operations. The more headings driven at one time the more quickly the work will be done; or with more shafts and a slightly different scheme the time could be shortened. An additional shaft should not add more than one cent a barrel to the cost of the oil recovered from 1000 acres.

W. D. BARRINGTON: I was the one who made the statement about 7½ years for development. That covered the period for complete development of the 1000-acre plot, but as soon as one block of repressuring and oil tunnels is developed, the oil recovery from repressuring could be started. This was in mind when formulating the plan for mining and ventilating.

F. A. W. LEWIN:† It seems to me some of the entries could be driven a little larger. The difference in cost between hand loading and mechanical loading for rock is 50 cents a ton and, by making the entries larger, a mechanical loading machine could be used and the

*Senior Mining Engineer, Pittsburgh Experiment Station, United States Bureau of Mines.

†Radburn-Fairlawn, N. J.

saving in cost by mechanical loading would be a great deal more than the cost of the extra size of entry.

LEO RANNEY: What would you think the limiting size?

F. A. W. LEWIN: The machine I have in mind which has proved more successful than any other in rock handling, used by the Pocahontas Fuel Company, requires a width of six feet and a height of 50 inches, so that an entry driven six feet high and seven feet in width would give plenty of room. We can load rock for about 10 cents a ton in cleaning up entries where the rock is more or less broken up.

W. E. FOHL:* How much would that be per foot?

F. A. W. LEWIN: I have not figured it out, but it could easily be calculated.

W. E. FOHL: The writer has constructed a lay-out to show a proposed development of an advantageously situated tract of 500 acres underlaid with an oil-bearing sand. This lay-out was made after consultation with J. French Robinson, engineer and geologist of the Peoples Natural Gas Company, and with the R. G. Johnson Company, contracting engineers.

The lay-out was intended for working either over or under an oil sand lying in a fairly uniform plane. Favorable grades have been assumed; and it was also assumed that the tract could be opened in the middle, giving a two-sided development.

The lay-out calls for shafts larger than those proposed by Mr. Ranney and Mr. Barrington. The dimensions of headings were generally seven by seven feet and 27 feet between centers, with crosscuts spaced 100 feet apart. The ventilating scheme calls for a separate split of the air current for each pair of development headings. Though Mr. Ranney's full scheme was not in view when the lay-out was made, it could be made to fit in with Mr. Ranney's scheme without material change.

*Consulting Engineer, Pittsburgh.

The lay-out is intended merely to give access to the oil sand with sufficient development to determine experimentally the best methods of extracting the oil.

On this amount of development the following summary indicates the cost as of July, 1930:

One 350-foot shaft at $155 a foot	$ 54,250.00
One 350-foot shaft at $145 a foot	50,750.00
Driving of headings; 35,000 cubic yards at $9.60	336,000.00
Plant cost plus fee	171,696.00
Total	$612,696.00

R. G. Johnson:* In arriving at the figures that Mr. Fohl gave you, I should say that mechanical mucking machines were figured to be used. The shovel considered was the type now used in the tunnels underneath portions of New York for the aqueduct for the water-supply of the city. It is necessarily heavier and more compactly built than the type used in coal loading.

In listening to Mr. Ranney's paper, I have been impressed by the fact that he passes over rather lightly one or two features that I would consider serious in the driving of shafts and tunnels in oil-bearing strata. Water and ventilation appeal to me as the biggest hazards to be met. He disposes of the water problem by simply saying that it would be sealed off. That, under any pressure at all, is a most difficult proposition, and it is a question as to just how effective cement grouting would be in oil-bearing fissures. It would probably be necessary to line with reinforced concrete a section through water-bearing fissures to seal behind it. This would be decidedly expensive, particularly if the shales are found to be broken to any extent.

The timbering of headings in shales where the roof is bad would present another item of expense that has not been figured.

Mr. Ranney also speaks of following the strata in the tunneling. If tunneling is to be done economically, the grade should be slightly in favor of the loads. If we were to follow the strata, we would probably have numerous dips which would mean swampy conditions, and require pumping. The present mucking machine requires a tunnel seven by seven feet in cross-section, and is air driven. We were

*President, R. G. Johnson Co., Pittsburgh.

instructed to figure the proposition under rather favorable conditions, but frankly I can not conceive of such an undertaking that would not encounter water and a gas or vapor which would be decidedly dangerous. I can imagine a vapor in such rocks that might even be fired by drilling sparks.

G. S. Rice: This discussion brings up one feature that I did not speak of in my previous remarks, but which may not be generally known. That is, that gas or vapor likely to be encountered has a much lower explosive limit in air than methane, the lower limit of which is five per cent. It was stated at Péchelbronn that the lower limit of the gas and vapor encountered is 3½ per cent. Furthermore, it is much more sensitive to ignition and may be ignited by frictional sparks. It is only under very exceptional conditions in the case of methane (which is the gas universally found in coal-mining) that ignition occurs direct from frictional sparks. A shower of sparks from a revolving wheel will not ordinarily ignite methane. It requires special conditions of heat and duration of sparks.

In the case of the Péchelbronn mines, they at first had ignitions caused by the use of picks, and in one case the dropping of tools in a shaft ignited the vapor. There were a number of serious explosions and fires in the mines, and when the French officials took charge in 1919 it was necessary to sink a second shaft for escape and for ventilation.

In the Péchelbronn mines they do not permit any electricity to be used except in the case of two pumps at the foot of intake shafts. Their power for drills and machines is compressed air. The management did not regard flame safety lamps as altogether safe in the oil vapor and required the general use by mines of permissible storage-battery electric lamps.

W. D. Turnbull:* The underwriters have recently drawn up a schedule for the approval of explosion-proof motors and control for operating in atmospheres containing explosive gases, such as found in and around refineries.

Leo Ranney: It is well to be prepared for any amount of gas that may be encountered. In the mine in Texas some tunnels were

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driven just a few feet above the oil sand and some just below. When first drilled some of the wells produced some gas from the oil sand, but in a few days the gas escaped through the pipe-lines to the surface. Drilling in the oil sand was done through a stuffing-box, but in the shale below or above the sand no discernible gas was encountered. In some places there might be a little gas in the shale, so I should advise being prepared for it.

Regarding the point that Mr. Johnson brought up about following the waves on the bottom of the sand, unless such waves were relatively large they could be ignored. In the eastern fields studied there seem to be no serious waves. It makes little difference whether the distance from the top of the tunnel to the sand varies two or three feet in different mine wells. The cores taken and studied have included the shales below and just above the oil sands. In these cores the shale has been very strong and seemingly quite impervious. We have not found any vertical fissures in those shales.

R. G. Johnson: Do you have cores showing these shales and sands?

Leo Ranney: Yes; from 50 feet above to about 50 feet below the sand.

R. G. Johnson: Diamond drill cores?

Leo Ranney: Yes.

R. G. Johnson: Did the roof hold well in those tunnels?

Leo Ranney: Yes, the roof stood up. In three years' time you could almost carry away in your hat the rock that fell from each hundred feet of roof.

A NEW SOURCE OF RAW MATERIALS FOR HIGH-TEMPERATURE HEAT INSULATION*

By J. Bryte Barnitt† and R. H. Heilman‡

The use of commercial heat-insulating materials has attained its greatest impetus during the present century. The increased cost of fuel, the demand for more flexible and accurate control of all processes employing heat, and the continued development of new products, have resulted in an extensive search for materials with longer life which will withstand severe conditions and conserve a greater quantity of heat. The most recent development in this search is the production of heat-insulating materials from minerals which consist chiefly of aluminum oxid. These materials have been produced with low thermal conductivities, excellent strength, and stability at the higher ranges of temperature. Their applications lie in the range from the temperature of boiling water to temperatures as high as insulation is deemed feasible.

In the lower part of this temperature range there is a variety of minerals which have been found efficient and satisfactory. In the upper part, however, the same chemical compounds that make excellent refractories are used. The distinction between refractories and insulating materials is based on physical rather than chemical characteristics. All insulation materials owe their insulating properties to entrapped air spaces, air being a very poor conductor of heat. In the vegetable kingdom, hollow cells and hollow fibers are quite common owing to the nature of plant growth; whereas in the mineral kingdom cellular structures are quite rare. In the two best known instances—pumice and diatomite—the air-cell structure is due to the natural mode of formation. On the other hand, it has been found possible to process certain minerals, thereby producing the proper cell structure essential for insulating purposes.

The bulk of refractory materials consists of but three chemical compounds—silica, alumina, and combinations of these in the form of clays. Of these, silica and clays have been extensively used in the

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production of heat-insulating materials, but alumina has had but little application until recently.

Silica came into use first because of the fact that all over the world there are extensive deposits of diatomite. The latter is formed by the deposition of the empty husks of elementary marine plants known as Diatomaceæ, species of which grow in both fresh and salt water, and which are microscopic in size. The husks are pure silica, but in deposition they are sometimes admixed with clay and organic matter. Many of these deposits are quite deep and extensive, and the material is naturally well cemented so that it can be quarried and cut to size and shape for use. When exposed to temperatures approaching 1600 degrees F., diatomite weakens and shrinks. This effect is due to the physical transformation from the natural quartz form to tridymite. In order to obtain an insulating material for use above this temperature, the diatomite is disintegrated, carefully purified, and then mixed with a small percentage of lime or clay, after which it is molded and calcined at temperatures above 1600 degrees F. to convert it to the form which is stable in the higher range of temperature. Silica insulating brick made in this manner will withstand temperatures up to 2500 degrees F. Such bricks are in some instances stronger and more dense than the natural diatomite and in all cases they have higher thermal conductivities.

Clay occurs abundantly in nature, but is naturally devoid of a suitable cellular structure. Clay insulating bricks are made in several ways, the most common of which is by mixing with finely divided organic matter which is burned out in the processing, thereby giving the proper porous structure, or by aërating with inert gases. Prevention of shrinkage and spalling are just as serious problems with bloated clay brick as with the more dense refractory products.

Pure silica has a melting-point of 3110 degrees F. and the higher melting clays soften at 3090 degrees F., whereas pure alumina has a melting point of 3720 degrees F.* Therefore, it would be logical to expect that aluminous materials offer a promising field for investigation as possibilities for high-temperature insulation. This is true particularly because of the higher melting-point range, the lower shrinkage with increasing temperature, and the well known refractory

*United States Bureau of Standards, Technologic Paper 10.

properties of alumina. The alumina obtained in the various methods of extracting it from aluminous ores by the Bayer and the fusion processes is of a very high degree of purity, and should therefore resist temperatures up to 3600 F. Alumina does not undergo crystalline transformations with consequent shrinkage or weakening until the temperature of recrystallization to corundum is reached. This temperature is considerably higher than the temperatures which insulating materials are required to withstand.

Recognizing the superior qualities of alumina as a refractory material, it was thought that there must be some form of it, either natural or manufactured, which, if of the proper density and pore structure, would have the qualities of an excellent heat insulator.

All of the commercial grades of bauxites occur in dense form and the pure alumina which is extracted from them is also obtained in dense form, so that these materials, although excellent as refractories, have thermal conductivities too high for consideration as insulators.

Our search for possible sources of raw materials which might be of value as bases for the manufacture of heat insulation has covered a large variety of aluminous materials. The following list includes a number of the more promising materials investigated:

1. Bauxite.
2. Monohydrated bauxite.
3. Alumina (Bayer process).
4. Alumina (fusion process).
5. Alumina fume.
6. Aluminum monohydrate.
7. Aluminum trihydrate.
8. Bauxite residue.
9. Bauxite residue (floated).

These materials were compared with a commercial grade of diatomaceous earth powder. In order to give a general idea of the composition of the materials investigated, the following tabulation of typical results of chemical analyses is presented:

TABLE I. TYPICAL ANALYSES OF MATERIALS INVESTIGATED

Material in powder form	Specific gravity	Al_2O_3 %	SiO_2 %	Fe_2O_3 %	TiO_2 %	CaO %	Na_2O %	Loss on ignition %	Origin
Diatomite	2.30	4.0	89.3	0.7	0.1	0.4		5.0	California
Bauxite (1)	2.55	58.4	5.1	2.8	1.9			30.3	Arkansas
Bauxite (2)		61.5	2.6	2.0	2.4			30.7	Demerara, S. A.
Bauxite (3)		59.7	1.8	4.3	2.4			31.8	Surinam, S. A.
Bauxite (monohydrated)	2.80	69.7	2.7	5.6	2.9		2.5	16.3	Surinam, S. A.
Alumina (1)	3.70	98.6	0.02	0.02	0.005		0.4	1.0	Bayer process
Alumina (2)	3.80	98.8	0.3	0.14	0.28	0.58		0.0	Fusion process
Alumina fume	3.60	63.9	27.3	0.18	0.05		2.2	1.8	Fusion process
Aluminum monohydrate	3.40	82.1	0.09	0.12	0.012		0.45	17.4	Processed
Aluminum trihydrate	2.45	65.0	0.1	0.008	0.005		0.25	34.7	Bayer process
Bauxite residue (1)	2.50	22.6	13.0	15.2	9.3	14.0	6.1	16.3	Bayer process
Bauxite residue (2)	2.50	29.6	13.6	17.8	14.2	3.1	6.9	12.9	Water floated

The comparative thermal conductivities of the materials investigated are shown in Table II and illustrated graphically in Fig. 1.

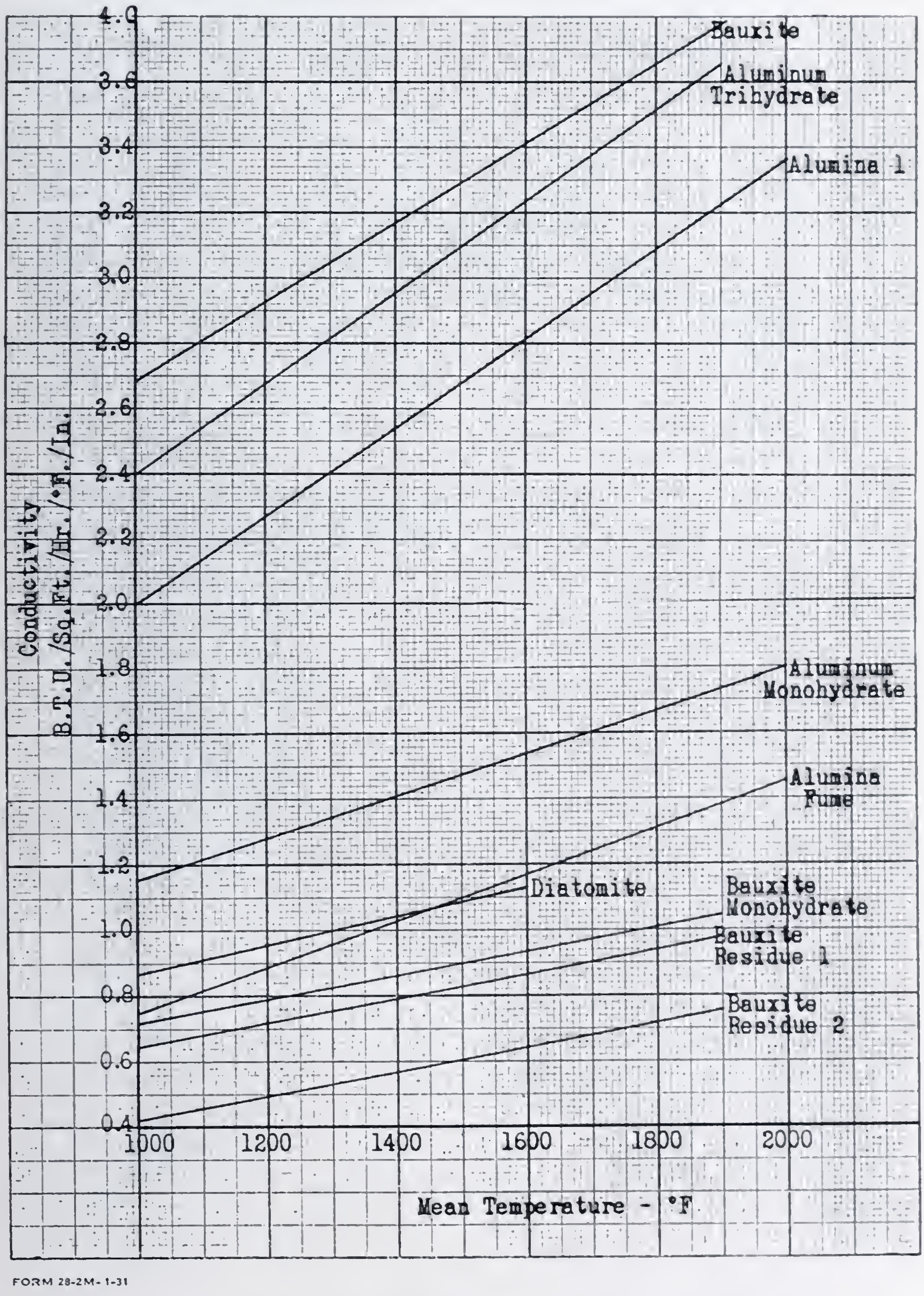


Fig. 1. Thermal Conductivities of Insulation in Form of Powder.

TABLE II. THERMAL CONDUCTIVITIES OF POWDERED MATERIALS INVESTIGATED

Material	Apparent density lb. per cu. ft.	Conductivity B.t.u. per sq. ft. per hr per degree F., per in.	
		*1000 °F.	*1600 °F.
Diatomite	22	0.864	1.134
Bauxite	92	2.680	3.410
Bauxite (monohydrated)	22	0.713	0.935
Alumina (1)	68	2.010	2.820
Alumina (2)	150	3.710	5.180
Alumina fume	40	0.750	1.175
Aluminum monohydrate	24	1.160	1.540
Aluminum trihydrate	80	2.400	3.240
Bauxite residue (1)	63	0.650	0.870
Bauxite residue (2)	50	0.420	0.650

*Mean temperatures.

Diatomite occurs naturally, widely distributed in various states of purity. In addition to its use as a heat insulator, it is extensively employed as a polishing agent under the name "tripoli." It is also used as a filtering medium, as a plasticizer in cements, and as an inert filler in many industries.

Bauxite is the result of the weathering of feldspathic rocks in tropical or semi-tropical climates. In bauxites the aluminum exists as a hydrate. It finds its most extensive use as a raw material for the preparation of alumina and, in turn, metallic aluminum and its alloys. The alumina, alundum, and corundum industries employ it in the preparation of refractories and abrasives, and it is the principal source of raw material for the alum industry.

Monohydrated bauxite is produced by the chemical treatment of raw bauxite. This material in powder form is highly porous, exceedingly fine, and of very low apparent density. These qualities make it an excellent material for heat insulation.

Alumina produced by the Bayer process is a fine granular material, its grain size depending on the method of precipitation. Its principal use is in the production of metallic aluminum, although quantities are used for refractories and abrasives. It can be used as an insulating material for high-temperature furnaces as it will withstand 3600 degrees F., but it does not have as low thermal con-

ductivity as many of the commercial insulating materials used at lower temperatures.

Alumina produced by the fusion process is formed in small hollow pills by the action of an air-blast on molten alumina slag. Its primary use is for the production of metallic aluminum. Formed into brick with a suitable binder it makes an excellent refractory. Its thermal conductivity is lower than that of most refractories, but too high to be classed as an insulating material.

Alumina fume is a very finely divided mixture of alumina and silica, and is a by-product of the fusion process. It can be used as a fine abrasive, as a filler, or as an insulating powder.

Aluminum monohydrate is produced from aluminum trihydrate by the same chemical process by which bauxite is converted to the monohydrated form. Being of high purity and low apparent density, it will withstand very high temperatures and is worthy of consideration as a source of raw material for high-temperature insulation.

Aluminum trihydrate is an intermediate product which is obtained in the manufacture of alumina by the Bayer process. Its chief use is in the production of alum. In special form and the activated condition this material has extensive application as a desiccant and adsorbent. It is particularly useful in the adsorption of moisture and impurities from air and commercial gases and can be reactivated for continued use.

Bauxite residue is the waste product which results from the extraction of pure aluminous material from bauxite. After having been water floated and chemically treated, it has been found useful as an inert filler, particularly in the rubber industry. It is also employed as a raw material in manufacture of Portland cement.

From an examination of the chemical and physical properties of the materials investigated, as indicated in Tables I and II, it is evident that only three of the more promising aluminous materials under investigation show evidence of possible use as heat insulators. These are monohydrated bauxite, aluminum monohydrate, and water-floated bauxite residue. Of these three, one of the most surprising developments was that floated bauxite residue should have such a low conductivity and still be of such high density in comparison with either of the monohydrated products or diatomite. Unfortunately the high density of this material tends to preclude its use as insulating

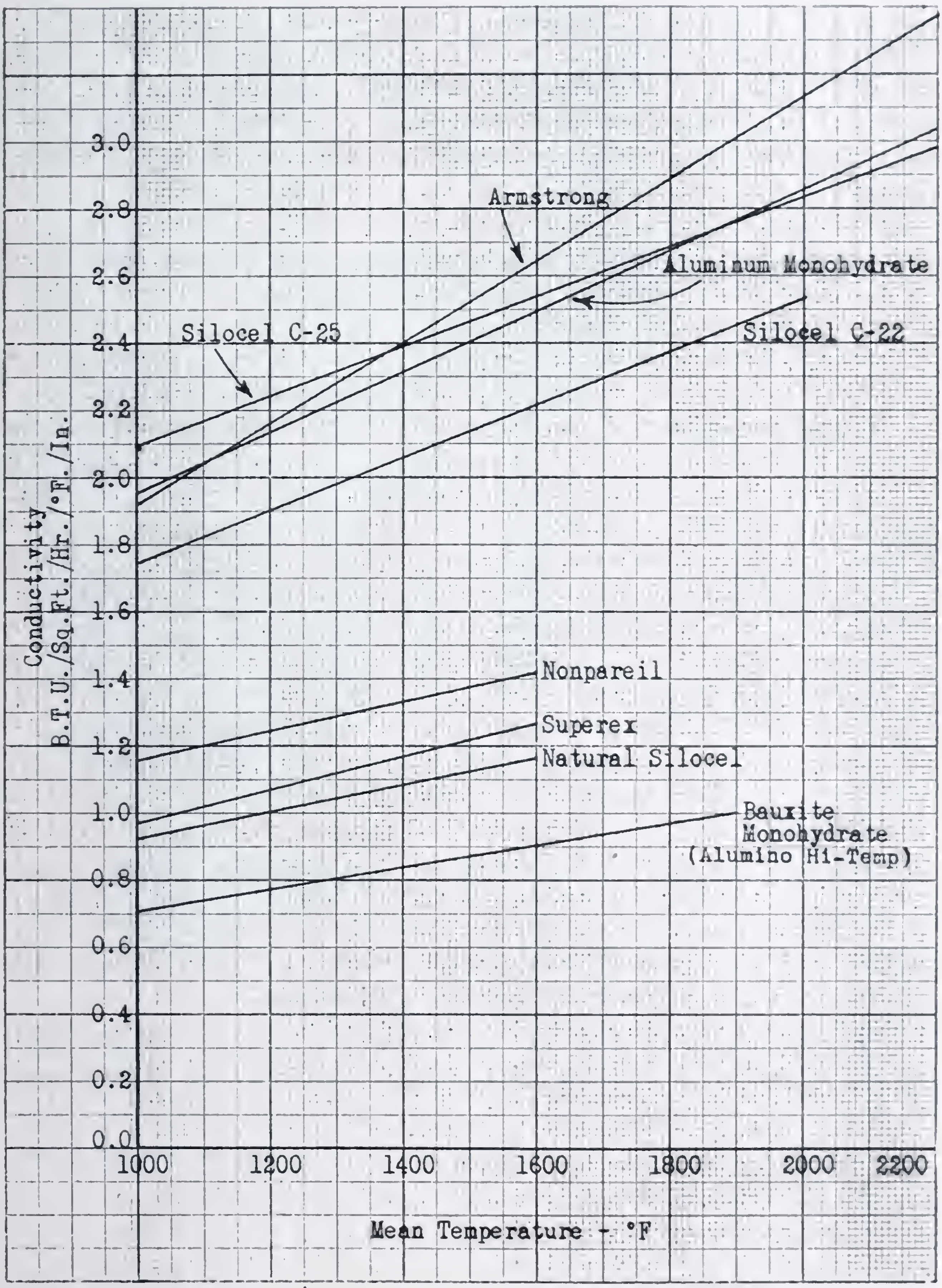
powder except in districts adjacent to its source. This gives the advantage on a weight basis to monohydrated bauxite and aluminum monohydrate. In so far as actual conductivity is concerned, aluminum monohydrate is somewhat higher than monohydrated bauxite. Obviously, aluminum monohydrate will have application in the higher temperature field on account of its greater purity and higher melting-point, but, due to the fact that it is made from a refined aluminous material, it is more expensive.

Further investigational work was then undertaken to establish the possible application of these materials to the fabrication of a molded type of insulation. Experiments with floated bauxite residue demonstrated the fact that this material, when molded into block form, showed marked shrinkage on drying which precluded its use in this field. However, the fact should not be overlooked that bauxite residue is an excellent insulating powder.

Investigation of the properties of aluminum monohydrate revealed the practicability of its use as a base for insulating bricks for temperatures as high as 2600 degrees F. The value of this aluminous material as a base is considerably enhanced due to its high state of purity which results in raising its fusion point to approximately that of pure alumina. Our tests have shown that insulating bricks employing aluminum monohydrate as the principal ingredient when molded and fired possess excellent insulating and refractory qualities.

After definitely establishing the properties and field of usefulness of both bauxite residue and aluminum monohydrate as heat insulators, the next problem was the consideration of possible applications of monohydrated bauxite.

From the data in the foregoing tables it is quite apparent that monohydrated bauxite in powder form is a superior insulating material. It compares favorably in density, stability, and insulating value with any of the existing commercial materials. An investigation was then undertaken to develop the application of this aluminous material in the form of a commercial heat-insulating block. Extensive experiments were conducted to determine the proper ratio of the various ingredients which would result in a molded product of high insulating value, low shrinkage, and satisfactory strength when exposed to high temperatures.



FORM 28-2M-1-31

Fig. 2. Thermal Conductivities of Insulation in Form of Brick and Block.

The results of the above experiments demonstrated that insulating blocks of excellent quality could be made in the laboratory. Quantities of the molded block were then manufactured and tested for their various properties and compared with other commercial grades of insulating material having similar application. From these tests the information presented in Table III was obtained. These results are shown graphically in Fig. 2.

TABLE III. THERMAL CHARACTERISTICS OF MOLDED INSULATION INVESTIGATED

Molded insulation	Recommended temperature	Apparent density	Conductivity B.t.u. per sq. ft. per hr. per degree F., per in.	
	degrees F.	lb. per cu. ft.	*1000 °F.	*1600 °F.
"Superex" block	1600	24	0.966	1.270
Natural "Sil-o-cel" brick	1600	29	0.925	1.170
"Sil-o-cel" C-22 brick	2000	36	1.750	2.220
"Sil-o-cel" C-25 brick	2500	44	2.100	2.540
"Nonpareil" brick	1600	30	1.160	1.420
"Armstrong" brick	2500	36	1.920	2.650
Monohydrated bauxite block	1900	27	0.710	0.910
Aluminum monohydrate brick	2500	45	**1.950	**2.500

*Mean temperatures.
†Experimental.

The data shown in Table III for monohydrated bauxite block were obtained from block heated at temperatures of 1000 to 1050 degrees F. The thermal conductivity of similar block dried at low temperature may be as much as 30 per cent. higher.

An inspection of the data in Table III reveals two very important facts—that monohydrated bauxite block has the lowest conductivity value of the materials investigated, and that it maintains its heat resistance without breakdown up to a temperature of 1900 degrees F. This is of paramount commercial significance, as it is a well known fact that there are many instances where the operating temperature of equipment is such that the uncalcined diatomaceous earth insulating materials do not have sufficient heat resistance (recommended temperature 1600 degrees F.) to enable them to be employed, and it is therefore necessary to use the calcined or higher temperature brick (recommended temperature 2000-2500 degrees F.).

TABLE IV. MAXIMUM FURNACE TEMPERATURE IN DEGREES F. FOR VARIOUS THICKNESSES OF MONOHYDRATED BAUXITE BLOCK

Thickness of firebrick, inches	Thickness of "Alumino hi-temp" block—inches												
	2	2.5	3	3.5	4	5	6	7	8	9	10	12.5	13.5
9	2510	2400	2350	2300	2250	2160	2130	2090	2070	2060	2040	2010	2000
13.5	2800	2575	2520	2460	2400	2280	2250	2220	2190	2170	2140	2070	2040
18	3020	2800	2720	2640	2560	2400	2340	2280	2240	2210	2180	2120	2090
22.5	3250	3050	2940	2840	2730	2520	2450	2380	2330	2300	2260	2180	2150

From Table III it will be seen that the insulating value of the calcined diatomaceous bricks is only a half to a third of that of the uncalcined ones or that of monohydrated bauxite block. It is obvious that an upward extension of the temperature range of from 300 to 400 degrees F. over that of the uncalcined material coincident with better insulating value will result in great economy, lower heat losses, lower first cost on account of reduced thickness of insulation required, and also reduced weight of material, which is of special importance, particularly in marine work.

Another very important feature is the fact that this new material can be molded into large blocks, thus greatly reducing the number of joints encountered when using the standard brick types of insulation. The greater size of the blocks also results in considerably lower cost of installation.

Table IV gives the optimum furnace temperatures which can be used when employing various thicknesses of monohydrated bauxite block on different thicknesses of refractory brick walls.

As an example of the use of Table IV, assume that a furnace built up of a 13½-inch fire-brick wall is operating at a temperature of 2400 degrees F. From Table IV it is shown that in order not to exceed a temperature of 1900 degrees F. on the hot side of the monohydrated bauxite block, the thickness of insulation should not exceed four inches. Similarly, with a wall thickness of 18 inches of fire-brick, the thickness of insulation should not exceed five inches.

Fig. 3 shows calculated heat losses, and outer surface temperatures for a nine-inch fire-brick wall, both uninsulated and insulated with increasing thicknesses of monohydrated bauxite block.

An experimental plant has been erected at East St. Louis (by the Philip Carey Company, Lockland, Cincinnati) to manufacture monohydrated bauxite blocks on a commercial scale. Large quantities of these insulating blocks, 9 by 36 inches and 12 by 36 inches, of various thicknesses have been fabricated and installed on many types of industrial furnaces and heating equipment. Results to date have been highly satisfactory and users of this new type of heat insulation have accorded it a very enthusiastic reception. Owing to the fact that the composition of these blocks is mainly of an aluminous material, the name "Alumino" has been given to this new type of insulating products.

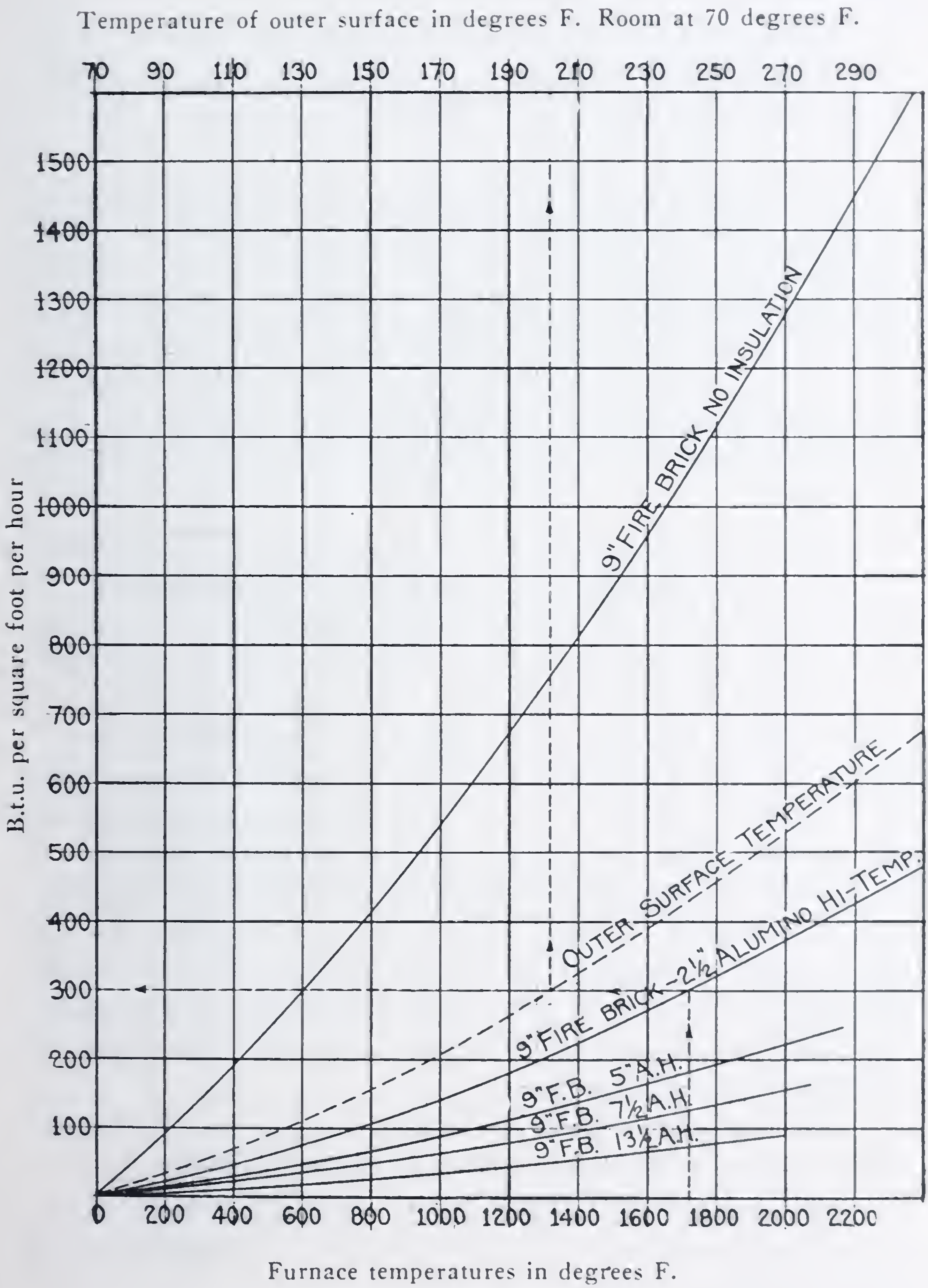


Fig. 3. Heat Losses through Furnace Walls.

DISCUSSION

JAMES ASTON:* We have two responses to invitations to contribute discussion of the paper, one from Mr. Nicholls, of the Pittsburgh Experiment Station of the United States Bureau of Mines.

P. NICHOLLS:† It is known that a new high-temperature insulation has been developed by the Philip Carey Company and the Aluminum Company of America and I believe that this is the first time that information on it has been presented. Its qualities as expressed by its thermal conductivity and specific weight indicate that it should be a welcome addition to those now available. I have no reason for questioning the reliability and accuracy of the values given in the paper; I therefore confine my remarks to seeking further information.

The heat-transmission data on the powders are very interesting and are quite an addition to those we already have for powders. The addition of the true specific gravity and screen size of the powders would make the information more valuable; I believe also that a microscopic examination might be of value and help to explain some of the results. Presumably the authors have made some attempt to explain the low conductivities of the two bauxite residues. From their chemical composition it is probable that their true specific gravities are higher than that of the bauxite monohydrate, but hardly to the 2½ times greater apparent specific gravity of the powders; therefore the percentage of voids in the residue is presumably materially less than that of the monohydrate, and in spite of that the conductivity is lower for both of them. One would think that the explanation lies in the type of contact between particles and that a microscopic examination might reveal it.

The loss by ignition for the powders is given and the temperatures at which the breakdown occurs would be an addition.

The apparatus and methods used in determining the conductivities are probably the same as described elsewhere; a reference to such literature should be given.

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†Supervising Fuel Engineer, Pittsburgh Experiment Station, United States Bureau of Mines.

The authors state that in making the blocks the monohydrated bauxite is mixed with certain binders, just as clay or lime is used with diatomite. Could they not give at least as much information as is given in the patent specifications?

Silica refractories have a higher conductivity than have fire-clays and, other factors being the same, it would be expected that an insulation with alumina as the main constituent should have an advantage. Although low thermal conductivity is a necessity with insulation, yet it is not the only quality, and there is need of establishing specifications for determining others such as strength (crushing and transverse) and some measure of friability.

The authors give recommended limiting temperatures; it is desirable that there should be some way to standardize their determination so that they will be comparable.

JAMES ASTON: We also have a communication from Mr. Keller that he will contribute to the discussion and we shall be glad to hear from him.

J. D. KELLER:* The authors are to be congratulated on their part in the development of a new heat-insulating material for moderate and high temperatures.

Most of us seldom stop to realize that we have not, and probably never shall have, a real insulator for heat, in the sense that we have insulators for electricity; that is, a material which will virtually stop the flow of heat—the pictorial advertisements of some manufacturers to the contrary notwithstanding. The best heat-insulating materials which have been available might with greater propriety be called heat baffles rather than insulators. Any development, therefore, which carries us a step nearer to the ideal non-conductor of heat is to be welcomed; and the monohydrated bauxite, which, according to the test data presented, shows approximately one-third better insulating ability, while it is capable of withstanding 300 degrees F. higher temperature than the insulating materials previously available for the moderate temperature range, appears to represent a real advance in heat insulation.

*Mechanical Engineer, Carnegie Institute of Technology, Pittsburgh.

The greater part of my discussion will be in the nature of a request for further information. One question that is important as regards any insulator is the variation of the heat conductivity with length of use. Many of the diatomaceous as well as the clay insulators, after having been in use for a considerable length of time, are found to have lost a part of their insulating value; in fact, their conductivity in some cases is found to have nearly doubled, as was indicated by some tests by the United States Bureau of Mines some years ago. Can the authors tell us anything of the properties of the new aluminous materials in this respect? Over how long a period have specimens been maintained at the recommended temperatures of use, and how much, if any, was the increase of heat conductivity?

Another problem in regard to conductivity is its uniformity. In most insulating bricks, considerable variation is found from one specimen to another, and, in the natural diatomaceous bricks, there is also a considerable variation with the direction of heat flow, the conductivity parallel to the layers or strata being greater than that at right angles to the strata. Mr. Heilman has made tests of all of these factors, and can tell us how much variation there is in the various materials.

In addition to low conductivity and the corresponding light weight, there are several other properties of insulating materials which must be considered in selecting them. These include mechanical strength, resistance to heat shock and to spalling, expansion, shrinkage, electrical conductivity, specific heat, resistance to slag penetration, and sizes and shapes available. Not all of these will be important in every installation, but each will be important in some installation.

Lack of mechanical strength has in many cases prevented the use of insulation outside the skewbacks of furnace arches, and under furnace hearths. It has also, in many plants, caused a prejudice against the use of insulation, on account of the excessive breakage in handling as well as the powdering or formation of dust. The latter is particularly objectionable in glass plants.

Excessive shrinkage when exposed to high temperature not only makes bonding with the ordinary refractory bricks impossible, but is largely responsible for cracking and spalling. Strange as it may seem, heat shock and spalling are closely connected with conductivity,

density, specific heat, expansion and shrinkage. We all know that of the insulators available up until very recently, even those recommended for use up to 2500 degrees F., have *not* been recommended for use in lining of furnaces "directly exposed to flame." The trouble is not so much that the flame is necessarily hotter than 2500 degrees F., as that the flame may produce a very quick change of surface temperature which can not penetrate quickly into the interior layers. The rate of temperature equalization, being proportional to the diffusivity (that is, conductivity $\div$ specific heat $\times$ density), is necessarily slow in an insulating material; the resulting differential expansion of the various layers sets up severe shearing and tensile stresses; and, since the internal bond of most such materials is weak, spalling inevitably results. The authors have doubtless tested the new materials in this respect, and it would be interesting to know whether this limitation of other insulating materials has been overcome.

Resistance to slag penetration is hardly to be expected in any insulator, but it would be a most desirable property in insulating materials to be used under furnace hearths, especially in iron- and steel-heating furnaces, where the slag formed readily penetrates through the clay bricks when these are used in the hearth. Low electrical conductivity, especially at high temperatures, would be of importance in some applications where resistor wires come directly into contact with the insulating material.

The question of sizes in which a given insulating material can be obtained is of great practical importance. The use of large blocks is, as stated in the paper, a real improvement; it means a smaller number of joints, less labor in laying, and less air infiltration where there is a negative pressure inside the furnace. At the same time, for some uses, the bricks of standard size will be preferred, chiefly from the standpoint of ease of application. With the standard-size insulating bricks, the various courses can be bonded with the clay refractories, and no other means of holding them in place is required; whereas the large blocks require either a metal sheathing or some other means of holding.

I should like to ask how the material would be applied to arches or to circular gas ducts, where there is quite a field for application of insulating material. Are wedges and arch brick available, or must the blocks or rectangular bricks be cut to shape?

James Aston: There have been so many important points raised in connection with the two formal contributions to the discussion that I think it would be entirely proper to ask Mr. Barnitt or Mr. Heilman to answer some of them now, before throwing the paper open to general discussion.

J. Bryte Barnitt: In our investigation of the thermal conductivities of aluminous materials our results indicate that neither compositions nor true specific gravities can be relied upon to predict the thermal resistances of the various materials. In many instances, however, a variation in the apparent density of a particular product is a direct function of its thermal resistance.

When apparent densities of different aluminous materials are approximately the same, it does not necessarily mean that their thermal resistances are the same. No doubt both the physical and molecular structure of the fine particles have much to do with the thermal resistance of the material. Bauxite residues are conspicuous in this respect in that they have very high thermal resistances coincident with high apparent densities. We are more or less at a loss to explain this except that bauxite residues are products resulting from a chemical reaction in which the alumina has been dissolved from the bauxite with caustic soda. This residue is exceedingly fine and highly porous, its porosity having been created by the extraction of the alumina. Bauxite itself does not have this highly porous character nor does it have any value as a heat insulator. Composition and specific gravity offer no explanation for this change in property. This is about the only explanation we can offer. In fact, Mr. Heilman's conductivity results on bauxite residues were quite a surprise to us. We know of no other such powder of such low thermal conductivity and high apparent density.

R. H. Heilman: Heat may be transmitted through insulation by three methods—radiation, conduction, and convection—the relative amount transmitted by each of these methods depending upon the nature of the insulating material.

In the case of finely powdered insulation, our tests have indicated that there is no heat loss by convection.

The loss by radiation would be very slight on account of the extremely small pore space in the bauxite-residue powder. Since the

radiation loss is proportional to the difference of the fourth powers of the absolute temperatures of the radiating surface and the receiving surface, it is apparent that, owing to the extremely small space between one surface and the other, the difference in temperature would be very small and consequently the radiation loss would also be very slight.

The loss by radiation may be considered from another angle. If we take, for instance, a one-inch air space and divide the air space in two by an infinitely thin partition having no insulating value, the amount of heat transmitted across the air space will be decreased by approximately one-half. If an air space of one inch is separated by two equally spaced baffles, the radiation loss will be decreased by two-thirds; with three baffles it will be decreased by three-fourths; with four baffles, by four-fifths, etc. It is very readily apparent, therefore, that in the case of very finely powdered insulation, where there are thousands of equivalent baffles per inch of thickness, the radiation loss would be practically negligible.

The only method, then, for the heat to be transmitted through this finely powdered insulation is by conduction. I believe that, since the heat is transmitted through this powder almost entirely by conduction across the small dead-air spaces and through the small solid particles of the material itself, the molecular arrangement and the physical nature of the bauxite residue probably account for the lower conductivity value. It can not be traced entirely to conduction through the air pockets, as other material having a greater porosity than this material has a considerably higher coefficient of conductivity. The conductivity of pure air with radiation and convection eliminated, at a mean temperature of 100 degrees F., has been found by various investigators to vary between approximately 0.14 and 0.19 B.t.u. per hour per square foot per degree F. temperature difference per inch of thickness with a temperature coefficient of about 0.2 of one per cent. per degree F.

It has always been the popular opinion that insulating materials having a very low apparent density would always show better insulating values than those having higher apparent densities. This assumption is not always correct, as proved by the results of the tests on the bauxite-residue powder. Other tests which we have conducted at Mellon Institute also indicate quite conclusively that this assump-

tion is not always true. For instance, one test on the well known 85 per cent. magnesia insulation indicated that when a particular sample was compressed with a corresponding increase in apparent density, the conductivity curves, taken before and after the sample had been compressed, crossed each other and the curve corresponding to the higher apparent density showed a lower conductivity value at the higher temperatures than the curve for the sample of lower apparent density.

J. Bryte Barnitt: I think Mr. Heilman has some comment on the physical properties of monohydrated bauxite blocks. The tests on breakdown, shrinkage, and strength have all been made under his direction.

R. H. Heilman: Mr. Keller has asked for recommended temperatures for this insulating block and also for the powdered insulation. We have shown the temperature limits of the materials by discontinuing the curves at the various mean temperatures; in other words, the curve for monohydrated bauxite is stopped at 1900 degrees F. This we considered the limit to which this material should be subjected. The same applies for the other materials. For instance, it is a well known fact that, if natural "Sil-o-cel" bricks are heated to a temperature much above 1600 degrees F., the material starts to shrink badly and to warp and crack. Bricks of natural diatomaceous earth are therefore not ordinarily recommended for temperatures above 1600 degrees F. The same reasoning applies to the other materials. The monohydrated bauxite insulating blocks can be subjected to a temperature of 1900 degrees F. with practically no shrinkage or deterioration. The limit of 1900 degrees does not necessarily mean that the material melts down at this temperature, but simply that it has reached the place where if a much greater temperature is encountered the material will start to shrink considerably. The monohydrated bauxite insulating blocks, or "Alumino" blocks, which is the trade name for this material, have a shrinkage of approximately one per cent. at 1900 degrees F. One per cent. is ordinarily considered low, but if you consider that this amounts to 0.36 inch in a 36-inch block, it is readily apparent that a material having a much greater shrinkage than one per cent. should not be used. Practically

all of the other former insulating materials recommended for a temperature of 1600 degrees have a shrinkage of between one and two per cent. at 1600 degrees F.

From what I have just mentioned, it is very evident that they can not be used much above 1600 degrees F. without producing considerable opening between adjacent blocks.

In regard to the question Mr. Keller asks as to using this material in furnace hearths, I do not think that this is possible. Owing to the very low density of the material, you could not expect it to stand a terrific strain such as would be present in a furnace hearth. The crushing strength of this material is approximately 100 pounds per square inch, which would be about seven tons to the square foot. This is ordinarily as much load as is put on insulation on the outside of the wall, but you might have, in addition to the weight of the furnace hearth, considerable strain due to expansion and contraction of the brickwork above the insulation. However, it has been found that insulating blocks in large sizes—while they may have a lower actual crushing strength than the higher fired insulating brick owing to the greater size of the blocks and to the fact that they are not nearly so brittle—will withstand expansion, contraction, and load strains in many cases much better than the fired insulating brick of higher crushing strength. The specific heat of this material is about 0.28.

In regard to how long this material will maintain its insulating value, I have in mind one specific example where this material has been under a temperature of about 1850 degrees F. on a glass furnace installation, and temperature readings taken a short time ago indicate that the thermal efficiency of the material is as good as when it was installed a year ago. We have also checked the permanency of the insulating value of this material by taking a sample and heating it to 2000 degrees F. in an electric furnace and then running a conductivity test on the sample after being subjected to this heat. It was found that the insulating value had been decreased about five per cent. by subjecting it to this temperature. We considered that since we recommended the material for only 1900 degrees F., if it were subjected to a soaking heat of 2000 degrees F. the results would be comparable with what would be obtained in actual practice by subjecting the material to 1900 degrees F. over a long period of time.

In regard to the difference of heat flow for the material in the two directions, we have not made any tests on this material in the way that Mr. Keller has mentioned. Our tests confirm those of Mr. Keller in that brick of natural diatomaceous earth, which has a laminated structure, shows an increase of about 40 per cent. in conductivity when the heat flow takes place parallel to the laminations. However, "Alumino" is molded hydraulically and does not show a laminated structure and, if there is any difference in the conductivity of this material when placed in the two different positions, it will probably be very slight. In any event, this material in the block form would be practically always applied so that the heat flow would take place in the direction of heat flow, as was the case with the tests. It is very seldom that, in building up a vertical wall with insulating blocks, the blocks would be placed with the nine-inch side down. However, when using brick sizes, this would quite often be the case.

B. A. Everlove:* Do you have any figures on the crushing strength of that same material at various temperatures?

R. H. Heilman: We have up to about 1600 degrees F. It is about 100 pounds.

B. A. Everlove: Do you have any figures on the residual strength?

R. H. Heilman: We have conducted shrinkage tests on this material all the way through to 2200 degrees F. At 1900 degrees F. it has a shrinkage of approximately one per cent.; at 1950 degrees, approximately 1½ to two per cent. From that on it shrinks very rapidly. It therefore has a very critical range at 1950 degrees F.

B. A. Everlove: What have you found out with reference to the type of material that will stand direct exposure to the flame?

R. H. Heilman: I believe that in some cases the fired material could be used in direct exposure to the flame if the conditions Mr. Keller mentions were not present. I do not think it would be suitable

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for resistance to slag, and ordinarily would not want to recommend it to take the place of the refractory brick.

Either brick or block can be shaped on the job to take care of any irregular surfaces that may be encountered.

In installing "Alumino" blocks very little cement is required, as ordinarily these blocks are not cemented up in the same way that a brick wall would be cemented. It is generally only necessary to fill up any cracks which may occur at the joints or where irregular surfaces occur.

MAINTENANCE ENGINEERING*

By R. H. Helick†

The design and construction phases of a structure are relatively brief and occupy but a few years of its life. After being built it must be maintained for perhaps a century, and on the quality of this care depends to a great extent how long it will last. Engineering supervision is therefore desirable.

Primarily, of course, long life must be designed and built in, and evidently it will pay to spend all the time necessary during planning and construction to insure lasting work. Unfortunately, we do not always have all the time we want to consider questions of design, as pressure is usually exerted to get the facility in service quickly. It is at this point that the maintenance engineer can be useful in helping to decide what forms of construction will be durable and likely to give least trouble during the life of the bridge. There is no question but that experience in maintenance work is valuable to a designing or constructing engineer, not only in bridge work but in any phase of engineering.

There are certain vulnerable points about a bridge and it may be useful to consider some of them. I believe that more trouble arises from devices for taking care of temperature changes than from any other thing. The majority of old bridges had simple roller-bearings, with little provision for keeping out water or for inspection and care. I have seen piers split lengthwise by the tremendous forces set up in them by frozen expansion bearings, and usually the removal and renewal of the rollers is possible only by the expensive construction of falsework and the use of heavy jacks. It is, therefore, evident that these bearings should receive great thought to keep them working during the life of the bridge. It would also be advisable, whenever possible, to arrange facilities for jacking up the spans on the piers in case the design proved faulty years after its construction, or the masonry bearings should need repairs.

The recent tendency has been to consider these expansion joints and bearings as pieces of fine machinery, and to provide facilities for keeping them clean and lubricated. It is good practice to inclose

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†Maintenance Engineer, Bureau of Bridges, Department of Public Works of Allegheny County, Pittsburgh.

them in oil-tight boxes, and if possible they should also be air-tight. The Seventh Street bridge over the Allegheny River has a pair of rocker nests under the south tower, and these rockers are in a box that is oil-tight except for a small clearance at the top. It was originally filled with a heavy asphaltic oil which was run in hot. A year later we tapped the boxes and an amazing quantity of water came out. There must have been nearly a barrel in each bearing. Of course we suspected seepage into the box through the small clearance space, but careful inspection revealed that no water was entering visibly even in the wettest weather. Then we had an idea which has been confirmed by experience, that the water was condensed from the air which was constantly blowing through the small crack. The movement of the rockers back and forth was forcing the heavy oil out of the clearance crack, and the air was depositing water to take its place. The oil was so stiff that the water lay on top of it. We fastened a small angle-iron around the box so as to break the direct draught and have had little water since. Therefore, we believe that rocker boxes should be air-tight as well as oil-tight. At the same time we decided that light, free-flowing oil was better than that which was thick and stiff. The clearances between the ends of the rockers and the sides of the boxes are usually so small that the heavy oil will not pass through them fast enough, and gets forced out of the clearance crack at the top of the box.

There is another school of thought in this matter, and one of the railroads in the vicinity uses heavy grease poured in hot. I have been unable to agree with this practice since the day we took off the sides of a rocker box on the Manchester bridge. This had been filled with grease of the consistency of vaseline, which proved to be churned to a honeycombed, sponge-like mass, and a large quantity of it had been forced out onto the top of the pier. Water was everywhere in the cavities and took a long while to run out. However, in the case of the older bridges with simple roller-bearings and no particular care taken to make them oil-tight, we force in heavy grease with a grease gun, and thus get fair protection against rust and insure positive lubrication.

Another weak part of the expansion joint is at the floor level, where the varying gap must be spanned in such a manner as to keep animal hoofs and human feet from getting into it. Where the expan-

sion is slight, a sliding plate usually suffices, but for large joints the plates must usually be supported by a toothed or interlocking arrangement under them. There are a number of types, but they must be carefully planned, as this is an excellent place to catch dirt and water, and there must be no possibility of the parts fouling each other.

The roadway of a bridge is the portion that gets the hardest wear, and I feel that we have not yet attained the ideal in this respect. Wood blocks were formerly used on account of their lightness and wearing qualities, but they are now taboo, except for indoor locations. They make an excellent machine-shop floor, for instance; but when exposed to the weather they swell slightly, and when rigidly confined at the curbs they buckle. Many of the existing large bridges were originally floored with these blocks, but after only a few years they had to be replaced with asphaltic concrete. They are also dangerously slippery in wet weather, although we have largely cured this condition by two methods. The Highland Park bridge over the Allegheny River has been covered with a tar and screening mat an inch thick, and although it does not adhere as well as could be desired we have had few accidents due to skidding since it was placed.

On bridges with railway tracks and flat grades we have used plates on the wood blocks with fair success. We have also used laminated wood floors with treated hardwood strips placed on edge and spiked solidly, protected by traffic plates for old bridges of this type, replacing wood blocks by a stronger floor of equal weight.

Asphaltic concrete has been used extensively, but it is likely to break out along the street-car tracks, and in some cases it becomes wavy. The maintenance costs promise to be rather heavy.

Brick and stone block are good, the latter probably the better of the two; but standard depth stone block is too thick for a bridge floor and a special thin block must be used. The surface texture is excellent, as it is anti-skid to a high degree.

Portland cement concrete has many advantages, but it is difficult to repair when worn out, as it is usually an integral part of the floor. A construction with a horizontal dividing plane has been suggested and would probably be practicable. We have been experimenting with armored concrete surfaces, consisting of steel grids pressed into the top of the green concrete, and so far these seem to be very good, though expensive.

The latest development is a floor only three inches thick composed of T-sections with the legs up. These are laid on steel stringers with a space of ¼ to ½ inch between their bottom edges, and connected by cross-bars. They are then filled with concrete. The construction is amazingly strong and light, and promises to wear for a long time. A small bridge with a floor of this kind was built last summer about three miles west of Tarentum, and it has been so satisfactory that this type will probably be used on a larger scale. It would be very suitable for fairly old bridges that can not stand the weight of heavy modern floors.

Another vulnerable thing about a bridge is the protective coating of the steel. This is usually paint, but we have used concrete molded in place, gunite, and the metal-spray process. The last was entirely an experiment, but so far it has given good satisfaction on the under side of the Sixty-second Street bridge at Sharpsburg, Pa., over the Pennsylvania Railroad tracks. This was a carefully done job, the metal being sprayed onto the new steel in the shop, and the care taken accounts for its success. I do not believe this method is adaptable to a bridge already in service over railroad tracks. It would be impossible to keep the metal sufficiently clean.

Gunite is of greater value than ordinary molded concrete, although recently the use of vibration has made the latter much more effective. It has been used extensively over railroad tracks where the effect of engine blast was very severe. This is the most trying condition as regards metal coverings and has given us more difficulty than any other phase of metal protection. In some cases a ceiling protecting all the steel above it has been effective, and in others it has been desirable to incase the steel directly. Both of these methods are expensive because of the added dead load and the necessity for increasing the steel sections to carry it. Consequently we are now giving this much study, and are considering the relative advantages of metal smoke shields. For this purpose the use of alloy steels seems advisable on account of the light weight which can be used. We recently installed an experimental smoke shield over the tracks of the Baltimore & Ohio Railroad Company under the Glenwood bridge and the metal in it was only about 0.056 of an inch thick. This is a chrome-nickel steel and it looks fit for a long life. The method of fastening a smoke shield is usually the weak point, since any play in

it is quickly aggravated by corrosion and the hammering of the heavy engine exhaust. We are now thinking of crimping light sheets of alloy steel over the lower flanges of girders and beams, thus in effect giving them a skin of this material.

Even with alloy steels, we still need paint. The paint policy of the Allegheny County Department of Public Works has been the outgrowth of years of dealing with contractors and manufacturers, and it may be of interest. We have consistently taken the stand that the manufacture of paint must be open to all bidders, and that patented or proprietary paints shall be avoided. This is not only required by law, but is the only way to avoid sales talks from a host of paint salesmen. We have considered that paint making is not too great a mystery for us to solve, and have designed our own paints, with the help of various agencies, including the manufacturers themselves. We get good paint at a very reasonable price. The same paint is used for construction work as for maintenance, and on small construction jobs the paint is frequently furnished the contractor out of the maintenance stock to avoid having small quantities of it specially mixed. Of course this is provided for in the contract, all bidding on the same provision.

All paint that is made is carefully supervised from start to finish. The manufacturer notifies the Bureau of Tests and Specifications when he is ready to make a batch, and a chemist is sent to the plant. He samples all the ingredients, watches the process of manufacture, and seals the barrels of paint. He then goes back to the laboratory and tests his ingredient samples, releasing the paint for shipment only when he is satisfied that everything is right about it. This applies to all paint, whether for construction or maintenance use. The application is also carefully checked when done by a contractor. An experienced painter is sent from the Maintenance Division as an inspector and he is on the job whenever work is done. The maintenance work itself is done by men in the employ of the County, and this obviates the necessity of watching a number of contractors on small jobs scattered all over the County. The small bridges are painted every three years because in that time the paint needs freshening up to increase the visibility at night, whether or not the film is badly gone. The large bridges are painted when they need it, and in some cases the interval is surprisingly long. The Washington

Crossing bridge (at Fortieth Street, Pittsburgh), for instance, painted first in 1924 still has its original coat and may go over to 1932, which would be a long time for a first paint film. This was the first big aluminum job, and it converted most of us to aluminum paint. The usual thing is that the first film needs reinforcement in a few years, after which the interval between paintings may be expected to increase. It is probable that the use of copper-bearing steel at Fortieth Street helped the paint greatly.

Modern masonry is good and we have learned to steer clear of concrete in sulphur water and poor sandstone in any water. Some of the old bridges are not so good in this respect, and it is often necessary to resurface old masonry walls or piers. For this purpose gunite has been used to good effect. However, when the abutments and piers are cracked and sagged, a considerably more thorough treatment is needed. For instance, there is the case of the Pennsylvania Railroad bridge over the Monongahela River on the Port Perry Branch. I think it was in 1922 that the splitting of one of the piers, due to frozen roller-bearings, got so serious that something had to be done. The logical thing seemed to be to build falsework on each side of the pier, take the load of the trusses on it, and tear down and rebuild the upper six or eight courses of stone which were badly shattered. However, after considerable thought, an inclosed and heated balcony was built around the top of the pier and operations were started in a safe spot by removing a broken stone which had fairly good support on each side of it. After the stone was removed, reinforcing rods were placed and some of them driven into the core of the pier and then the hole was filled with rich concrete. While this was setting, another stone was removed on the opposite end of the pier and the same process repeated. The concrete blocks were dated by scratches on their surfaces, and no work was done near a new block before it was old enough to take the load. In this way a crew of about four men worked a whole winter and entirely rebuilt a pier top under traffic. The estimated saving over the falsework method was about $20,000. This indicates that much can be done in the way of underpinning and casing old masonry to make it useful. A number of our arches inclose older ones which proved inadequate in size or carrying capacity.

There is one thing of the utmost importance in maintenance work, and that is the inspection system. There must be regular, systematic inspection, the points of greatest possibilities for danger being given major attention. The question of personnel is vital and a good inspector is rare and worth having. He must above all be honest, and he should be a pessimist. The engineer to whom he reports must supply the necessary optimism. In order to help the inspector, the design and construction of a bridge should consider everything that will facilitate access to the vital points. I am in favor of inspection galleries and stairways so that the portions under the floor and at the bearings can be readily examined. Too often it takes an entire steel gang with tackle and stages to get at a bridge to inspect it.

After trouble is found by the inspector or engineer, a good repair organization is needed to correct it. For public work there should be a permanent force of the proper size for the work to be done, and it should be well equipped. Letting contracts for small repairs is cumbersome and wasteful, and in emergencies the contractor is usually not of much use. Bridges are built to handle traffic, and when something happens and the traffic is stopped, quick action is necessary to get it going again. Only a well equipped force of specialists can be relied on for this. The maintenance man must always have in mind the necessity for keeping traffic moving safely.

There are times when the engineer must use other methods than formulæ and mathematics. This is illustrated by our experience with the old Forty-third Street bridge. It was imperative that we should keep it in service until the new Washington Crossing bridge was opened. Many of you will remember that old wooden basket, which mingled timber arches and stiffening trusses until the stresses were quite indeterminate. It had been blown upstream by the wind so that it was two feet out of line at the middle of the spans, and the cross-section was decidedly rhomboidal.

We used our engineering training to truss it up all over with steel cables, and then we depended on constant supervision of its action when under load to assure us that it would stand. That was using the same sense as the elephant when he tests a bridge before intrusting his weight to it. This illustrates the fact that experience is important in maintenance work, and often a small crack will tell a story that would be unnoticed by the novice. For instance, the

retaining wall at Twenty-sixth Street supporting the fill below Bigelow Boulevard fell in 1920. For about two weeks before it upset we knew what was going to happen and were to some extent able to prepare for it. Slight indications must be looked for if precautions are to be taken against disaster.

The investigation of the condition and weight-carrying capacity of old bridges is an important part of bridge maintenance. Owing to the tremendous revolution of transportation methods in the past twenty years, many bridges which formerly were good enough are now obsolete. It is impossible to rebuild them quickly enough, and the most important ones must be taken first. Out of a total of 350, there are about 140 county bridges which have load limits, and this does not include 17 of the 60 bridges taken over by the State Highway Department last year. The problem of load limitation is, therefore, an important one, and we have posted all bridges which are not good for the state legal limit of 26,000 pounds gross weight for four-wheeled vehicles. In addition, we have a permit system for heavier loads, whereby permission is given to cross specified bridges with a particular load if an investigation of stresses in these bridges shows it to be safe to do so. This is a constant function of the Maintenance Division. When bridges are damaged by loads with or without a permit, we collect the cost of repairs from the party responsible.

The load limits in practical use are two—11,000 pounds and 18,000 pounds gross weight. These correspond to certain classes of trucks, which are shown by the license plates of the present admirable system. Trucks of the R, S, and T types can use bridges of the 11,000-pound limit, while the U and V types are permitted in addition on the 18,000-pound ones. Types W, Y, Z, and ZZ are allowed only on the so-called "unlimited' bridges. The selection of only two limits is a bit arbitrary, but it enables one readily to observe trucks that are probably exceeding the limit. If there is strong enough presumption, the truck can be weighed to make sure.

The weakest part of old bridges is usually the floor, and heavy loads may damage floors even though they may not injure the superstructure proper. I know of very few exceptions. Once the load is taken by the trusses it seldom causes trouble, and then only in the compression members. The tension members rarely worry us; in fact, we have a few cases where only one of a pair is working. We know

how to fix that and are doing it, as shown in Fig. 1 and 2, but experience shows that there is an ample factor of safety in most tension members.

Fig. 1. Inactive Diagonal Bar.

For a while we worried about the kinks sometimes put in tension truss web members by accidents on the roadway. We finally got some test specimens, kinked them and pulled them. To our surprise the kinks were the strongest parts of the bars, and they invariably broke elsewhere, the reduction of section being least at the kinks. Then we decided that the cold working of the steel was responsible for the increased toughness. We no longer worry about kinks in ten-

sion bars, unless they are actually cracked, but go right after those in posts. Compression members in old bridges can readily be overstrained, and a slight bending, or damage to one of the outstanding

Fig. 2. Device for Tightening Inactive Diagonal Bar.

flanges, may be critical. Buckling of lattice-bars is the most noticeable symptom of trouble.

We see, then, that the maintenance engineer is concerned not only with problems of physical condition, but must be in touch with the effect of the loads applied to a structure, and able to give advice as to probable future conditions relating to new bridges.

DISCUSSION

C. S. Davis:* It is gratifying to know that the bridges of Allegheny County are receiving such thorough attention and that their maintenance is of such a high standard as indicated by Mr. Helick's very interesting address. It is to be hoped that bridges in other localities will receive equally good care.

I would like to ask Mr. Helick if he has considered an asphaltic material for waterproofing the exposed surfaces of concrete bridges, many of which have recently been built in Allegheny County. While it is common practice to waterproof underground surfaces with asphaltic material, it is not usual to waterproof exposed surfaces in like manner. There is no lack of evidence showing the need of protection of this character. Concrete is porous and, unless it is protected, water will penetrate and cause serious damage. I believe an asphaltic material would successfully keep out water, and that exposed, as well as underground, surfaces should be waterproofed.

Structures waterproofed with an asphaltic material would be black instead of gray, which might not appeal to esthetes. Black, however, is being used for exterior finish in buildings and might not be objectionable in a bridge. Personally, I would like to see a sample, and believe it desirable for the County to try it out on some structure in a location convenient for observation. If this treatment should not be found objectionable on account of color, it might result in prolonging the life of our concrete bridges.

P. J. Freeman:† Allegheny County uses bituminous materials for waterproofing concrete masonry at points where the black surface is not exposed to general view. Up to this time we do not feel that the public would be willing to have large areas of concrete painted black, and for that reason we are planning to try out aluminum powder carried in a tar vehicle. Up to this time no asphaltic vehicle has been presented to us which would be satisfactory for use with aluminum powder, and we are expecting to use tar as a final coat to make a light-colored surface on some concrete structure in the very near future.

*Consulting Engineer, Pittsburgh.

†Chief Engineer, Bureau of Tests and Specifications, Department of Public Works of Allegheny County, Pittsburgh.

I thoroughly agree with Mr. Davis's suggestion that mass concrete should be protected from the weather, and, so far as I am personally concerned, I would be willing to use a covering material which is black, but engineers, in general, are bitterly opposed to the use of a black material, and I am afraid that the people, in general, would also object to such a color, and for that reason we are proposing to try out the aluminum color as a means of covering up the black waterproofing material.

C. S. Davis: I would suggest using a black treatment on some prominent structure in order to get a reaction from the public.

CHANGING TREND OF POWER DISTRIBUTION IN THE STEEL PLANT*

By S. S. Wales†

The early conception of the proper uses of blast-furnace gas was the heating of hot-blast stoves and the production of power for blowing-engines. As this service—including 30 per cent. for stoves, and the poor efficiency of low-pressure, non-condensing engines, then in common use—would account for possibly a little more than 50 per cent. of the gas produced, and no other market was available, the economics of the case dictated the use of boilers of low initial cost, with their attendant low rating and efficiency.

This was good engineering at the time, as there was no economy in saving gas in expensive, high-efficiency boilers and wasting it at the blast-furnace "bleeders," and, while no great effort was expended in cleaning, the extra cost of firing unnecessary gas was represented largely by the increased size of piping required. This still left a large percentage of gas to be wasted, and some furnace plants went out of their way to find a market for it, by installing special power-stations, to supply outlying manufacturing plants not strictly within the heat balance of the making and finishing of steel.

When the combination of the furnace plants and rolling-mills in the same group began to appear, an additional home market was presented for the steam-producing ability of the furnace gas to supply the power required for blowing the Bessemer converters and for driving the rolling-mill engines. This increased demand required boiler plants of higher efficiency, and what was formerly waste gas became a valuable by-product.

This need for power for mill operation further demanded the more efficient use (as well as production) of steam, so that more economical engines, such as compound condensing, using higher steam pressures, developed for driving rolling-mills. Eventually these highly developed steam-engines were also applied to electric power generation as electrification began in the early 'nineties.

This era was marked by the rapid replacement of small steam units, from 10 to 50 horse-power, by electric motors, but the general

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†Chief Electrical Engineer, Carnegie Steel Co., Pittsburgh.

electrification of the main rolls, with motors of from 500 to 5000 horse-power, could not be economically entered upon while the power must be produced in the electric station by steam-driven units no larger or more efficient than the mill engines the electric motor would replace.

Undoubtedly the basis of the present advancement in electrification of rolling-mills is the development of the very efficient, compact, high-speed, turbine-driven generator. While the steam-turbine is not fitted by construction or speed to direct application to the mill coupling it is able to supply electric power from large generator units, many times the size of the motor driving the rolls, at a consumption of steam per horse-power delivered, which showed an appreciable saving over the engine-driven mill. The saving and return of steam to the general system, from the trial electric units, was so great as to encourage further electrification, and the steel-mill power-plants grew rapidly in capacity and size of units until in some cases they rivaled the local public-service plants in size and required a constantly increasing amount of gas as fuel.

This growing demand for gas reacted to induce greater economy in what were originally assumed to be its natural and most important uses, and we find blast-furnace stoves using 18 per cent. of the gas produced instead of 30 to 35 per cent., and turbo-blowers of high speed and efficiency replacing the older slow-moving reciprocating blowing-engines, until by far the largest demand for blast-furnace gas to-day is for the generation of electric power through turbines, by means of steam produced in very efficient modern boilers of large unit capacity, at high pressures and ratings.

At present, the sentiment is changing, and studies are being made of the economics of using fuel, already in a gaseous form, under boilers where solid fuel can be very efficiently burned, and at the same time using solid fuel to obtain gas not too efficiently produced for metallurgical purposes, such as the open-hearth steel process and the heating of steel for rolling. There are districts in this country where at one time this question was not very pressing due to the large amounts of low-cost natural gas available for these purposes, and some plants located within reach of large producers of by-product coke-oven gas may never be affected. However, to the industry at large, the thought of using blast-furnace gas, probably enriched in

some way, as a metallurgical fuel is so attractive that some large blast-furnace electric power-plants are facing the possibility of being reduced to a coal basis.

It is customary to think of economy in steel-producing methods in two figures, yet, with the by-product fuel eliminated, and purchased coal substituted, the plant power-station can not return much over five per cent. on its investment, in addition to finding itself competing with, and theoretically in the position of a trespasser on the domain of the public utility companies, which are well able to take their place and are worthy of support.

This problem is not a simple one, in view of the enormous investment in generating equipment already made, which apparently must be operated so as to show some return, although without such investments a better economic route might be followed. In the beginning, with a blast-furnace by-product, containing millions of heat-units going to waste every hour, the plant electric power-station needed no apology. Now with this same by-product demanded for the melting and heating of steel, the plant power-station is flatly on the defensive against the highly developed public-service station with its enormous "tie-in" resources and economical production.

The life of the steel-works power-plant may be prolonged by utilizing coke braize, if available, and waste heat from the open-hearth furnaces, where that process is used, but the latter entails the cost of an entirely new boiler equipment and the abandonment of the blast-furnace boilers.

Still another side of the problem presents itself in this country, due to the enormous supply of cheap fuel. Existing plant power-stations are cheaper running than standing still, as the overhead must be met in any event, and, if they are kept idle and power is purchased, a second fixed charge has to be met in the shape of utility "ready to serve" charge. So, while it is economically wrong for a company manufacturing steel to engage in making electric power beyond the use of its by-product heat, still it may be financially right under existing circumstances. Of course, where there is a difference in frequency between the plant power-station and the public utility, requiring all purchased power to be delivered through frequency changers, the difficulties of purchasing power are increased and existing works power-plants are in a stronger position. We thus have the

paradox that, while general economics would indicate that the proper path to follow is to use blast-furance gas, by-product gas and tar for metallurgical purposes, and coke braize or open-hearth waste heat for power production, augmented by public-service power, it might not save money to make the change with our low fuel costs.

In Europe, where the price of fuel is high, it has been found profitable to follow the route suggested above, and purchase power, even to the length of selling by-product gas to the utility companies, and we may safely expect Europe to lead in this line of development for many years to come. However, the American engineer should keep in close touch with European progress and study his present and future problems with these possibilities in mind so as to avoid expensive installations, which may have to be written off before they have served their useful life.

DISCUSSION

J. A. Dent:* I would like to know whether it is necessary to go to the same degree of care in cleaning the gas when used for metallurgical purposes as when used for power purposes?

S. S. Wales: As far as I know it is not, although it must be carefully cleaned mechanically to remove dust to prevent filling up the checkers. In using powdered coal it was found that about 1000 pounds of ash deposited in the flue and checkers for each heat in a 50- to 60-ton furnace.

M. R. McConnell:† Is there any better load-factor in the use of blast-furnace gas when used for open-hearth heating than when used for power purposes? Could you possibly use the gas to better advantage in the open-hearth than in the power-plant?

S. S. Wales: I believe it would have a much better load-factor in the open-hearth furnace than in the boiler house. Under the modern method of blast-furnace operation, where the blast is not taken off while tapping, the production of gas may readily be more uniform. Under the old method of operating an 11-furnace plant, with all

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†Power Engineer, West Penn Power Co., Pittsburgh.

furnaces operating, the gas production was equal to that of nine furnaces.

H. P. MATHIEU:* Has this new trend of power distribution in the steel plant been recognized long enough for a new plant to be built embodying the principles discussed?

S. S. WALES: In some Canadian and European plants they are using blast-furnace gas. One German plant is actually selling by-product coke-oven gas to the city for domestic use and buys all its electric power. They release this coke-oven gas through the use of blast-furnace gas for metallurgical purposes.

J. A. DENT: How does the temperature you get from blast-furnace gas compare with that from by-product gas?

S. S. WALES: With by-product gas, the temperature would be higher.

B. R. SHOVER:† Mr. Wales has given a very clear idea of how and why steel-mill power has reached its present high development, but he omitted one step in its progress, namely, the gas-engine, and I should like to take advantage of this opportunity to explain why so many of us twenty-five or more years ago sponsored its installation. No excuses are being offered, because at that time the most economical way to generate electric power from blast-furnace gas was by means of the gas-engine. Within a few years, however, the increase in size, speed, efficiency, and reliability of the turbo-generator, together with a corresponding decrease in the unit cost, has placed it so far in advance that coal would have to cost about ten dollars a ton before the gas-engine could be considered as a competitor.

Mr. Wales also points out the possibility (even the probability) of another change in the power situation in steel-works which is of even greater magnitude than any of its predecessors—the use of gases for metallurgical purposes instead of for the production of power. This practice has been proved correct in a number of European plants

*Dravo-Doyle Co., Pittsburgh.
†Consulting Engineer, Pittsburgh.

and has been adopted as basic for the huge steel-works now under construction in Russia, so that many engineers believe it will be followed in this country in spite of the relatively low cost of coal here.

Many investigations seem to prove that, in view of the low cost of purchased power, industrial works, except in special cases, are warranted in generating electric power only to the extent of using what would otherwise be waste heat.

In deciding to make such a change, every steel-works now generating power from gas will be obliged to give careful consideration to the question of firing coal under its boilers, as compared with the abandonment of its power-plant, and certainly no new steel-works would seriously consider generating all its own electric power. Because of the possibilities of obtaining such large blocks of additional power, public-utility companies located in steel-producing districts should make intensive study of this entire problem, not only for the purpose of providing their salesmen with valid arguments, but also to enable them to care for the additional demands which apparently will be made on them in the not distant future.

S. S. Wales: The gas-engine may, individually, be the most efficient power producer in existence, but where several are run in parallel on alternating-current generators, they can not be run with one or two of the four cylinders inoperative, without great distortion of the wave form, and resulting hunting and heavy surges on the line.

N. C. McKinnon:* The Homestead steel plant is supplied largely by by-product gas from the blast-furnaces across the river. They figure on 25-cycle current. In some cases they transform the direct current. It costs less than half a cent per kilowatt, and besides supplying that big steel-works they still have enough gas to use in the stoves of the furnaces.

*Sales Representative, Lewis Corporation, McKees Rocks, Pa.

THE STEVENS OPEN-HEARTH FURNACE*

By Thomas G. Kust†

The Stevens open-hearth furnace was primarily designed to establish and maintain, within the furnace, conditions that will promote more uniform metallurgical reaction; conditions that will reduce loss of metal and result in greater yield; and conditions that will reduce inclusions, and produce better steel.

It was also the purpose to attain the highest thermal efficiency by better combustion and maximum heat recovery, and to speed up and therefore increase the tonnage output of a given size of unit.

To carry out this program entailed radical changes in methods of construction and operation from what was established practice.

Mr. Stevens tried for years to interest his clients and others sufficiently to allow him to build a furnace embodying his ideas, but not until 1926 did he succeed in his efforts.

His first furnace went into production early in 1927 and demonstrated immediately and fully the correctness of his ideas, the results exceeding all claims made by him. It was a departure in many respects from the then existing practices, and the methods of operation were so far removed from the experience of the melters that it took considerable effort to train men to the required new habits and mode of thought.

This first installation was a 30-ton acid furnace and, after it established new records, many persons prominent in the steel industry claimed that such methods would not work on basic practice.

The next installation made by Stevens was a 100-ton basic furnace. This was put into production early in 1929. This was followed by the installation of three 50-ton basic furnaces and one 30-ton basic furnace.

It takes time to demonstrate new methods, and the operating force must become familiar with modified practice which changes the composition of the charge, and the methods of handling the heat. These changes must be brought about gradually and the capabilities of the new equipment proved to the operator. He must be convinced that a radical change in methods will not injure his heats or burn down the furnace.

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†Vice-President, Arthur L. Stevens Corporation, Chicago.

For this reason the Stevens Corporation was not willing to make public the details of operation until sufficient time elapsed to make it possible to state with authority—based on actual, continuous practice—the results obtained. Even at the present time we feel that the full capacity and capabilities of the Stevens furnace have not been realized.

One of our clients, when urged by Mr. Stevens to conduct additional tests and investigations which would further reduce additions and improve the quality of the steel, stated that the results now were so much better than anything previously accomplished that he was satisfied. It is, of course, easily understood that in the average plant it is difficult to carry out refinements of processes when interest is centered principally on the subject of production.

The Stevens furnaces, both acid and basic, have been in continuous operation sufficiently long to establish the principal facts of their outstanding advantages.

In operating a 100-ton basic furnace with all cold charge, making a variety of steel ranging from 0.05 to 1.15 per cent. carbon and comprising deep-stamp, strip, structural grades, axle, spring, and alloy steels, the yield in ingots from metallic content of the charge ranges consistently from 94 to 96 per cent.

The fuel consumption with charges made up entirely of cold material is approximately 3,500,000 B.t.u. per gross ton of ingots from tap to tap. The refractory costs are about one-third of what they were and are in other practice.

Our campaigns are longer. The first campaign of our 100-ton basic furnace went 534 heats before shut-down, and, had a few minor repairs been made, could have run three hundred additional heats. The bottom was burned in before starting this campaign. During this first campaign no slag was removed from the slag pocket, and the only cleaning done was to remove dust accumulation from flues to stack and between rider walls. The second campaign ran 532 heats when the furnace was shut down, not for repairs, but for lack of business. It could have run much longer. It is now on its third campaign.

We find that less material is needed in making bottom between heats than in other furnaces of corresponding size and similar operation. We find that, when the charge is made up of pig-iron and scrap,

about one-third less pig-iron is required for definite carbon content in the steel. This results in lower cost when pig-iron costs more than scrap. If hot metal were used we would use more ore, which would also result in lowering of costs. We also find a very marked reduction in manganese and other additions required, and this results in a decided saving in cost.

Because we use fuel economically many have assumed that the principal saving effected by the Stevens furnace has been in cost of fuel. This is not so. In one case where we effected a total saving of approximately three dollars per ton of ingots, the fuel saving was only about 75 cents a ton. The advantage resulting from better steel, which has been fully demonstrated as being made in Stevens furnaces, has effected savings which are difficult to estimate, but these indirect savings are admitted to be large.

We produce more tonnage from a Stevens furnace with a given size of unit owing to faster melting and less time lost for repairs. With proper charging facilities and a fair grade of scrap and with an all cold charge (no hot metal) our 100-ton furnace will make 16 heats a week, and produce from 70,000 to 75,000 tons of ingots a year. Remember, this is with a cold charge. If you consider the increased tonnage over which to distribute labor and fixed charges on the plant, it will be readily seen that this feature has an important bearing on the cost of production.

To accomplish these results requires a furnace designed upon correct principles and operated in strict conformity with the right methods. We have had representative men of the steel industry inspect our furnace and fail to comprehend just what we do. One man found that we use insulation and informed Mr. Stevens that the results we obtained are due to that alone; another man thought results were due to the burner used; another noticed that we use draft-gages and thought results were due to the regulation of the draft; and still another, after seeing a Stevens furnace, placed a CO_2 recorder on his furnace and claimed he could accomplish as much with that as Stevens could in his furnace.

The results obtained in the Stevens furnace are not due to any kink of design or to any one factor, but to a well thought out development involving the design and construction of the entire furnace

from foundation up, to fulfil the requirements by which a different method of operation may be accomplished for definite ends.

Open-hearth steel making is essentially an oxidizing process. Heretofore it has been considered essential (and is still so considered by many steel melters) to depend upon the oxidizing action of the flame to reduce carbon, etc. While all other elements were weighed and measured into the furnace, oxygen has been allowed to run wild with no means for its accurate control. Common practice has been to operate on stack draft with nothing but the crudest means for regulating the quantity of air entering the furnace. It was considered necessary to maintain brick walls by having them laid with open joints to allow cold air to infilter, with the result that by the common method of operating, large volumes of cold air entered the furnace. This condition resulted in lowering of the flame temperature, increasing fuel consumption, slowing up of melting, and producing a strongly oxidizing atmosphere which not only reacted upon the carbon but also upon the metal itself, causing heavy loss of metal.

One result of such practice has been to limit the amount of heat recovery possible from the regenerators. Another result is the wide variation in carbon content on melting down, requiring variation in the treatment to condition the heat before tapping.

The Stevens method is to maintain practically a neutral atmosphere in the furnace with the air intake limited to actual fuel requirements for perfect combustion. To accomplish this it is evident that fuel and air must be measured in correct and definite ratios. Furthermore, to make such measurement effective, practically all other air must be excluded.

It is obvious then, that stack draft must be neutralized or balanced so that atmosphere in the furnace is as nearly as possible equal to atmospheric pressure outside. It naturally follows that the air should be supplied by a method independent of the stack draft, and the stack in the Stevens furnace merely acts to remove the waste gases but in no way governs the volume of air introduced. It is also evident that to maintain such conditions it becomes essential to close all openings into the furnace and construct the furnace as nearly airtight as possible.

The system entails the accurate ratio of air and fuel, and the prevention of the infiltration of cold air which automatically requires

stack draft control in the sense that establishing certain conditions necessitates the observance of contributing factors.

With these conditions established, it is evident that the highest temperature of flame will be obtained. This contributes to fast melting and has an important metallurgical bearing on finishing the heat. It also enables fuel to be used with the greatest economy.

By the reduction in fuel which is accomplished in Stevens furnaces, combined with the elimination of the excess air, the waste gases are reduced in volume to less than one-half of what has been customary. This reduces the velocity of gases and the cutting action upon refractories; carries over less slag to the slag pocket and regenerators; prolongs the life of refractories; and enables us to carry on longer campaigns.

This system entails different methods of construction and it is interesting to note that the first Stevens furnace made a campaign of over 2500 heats, on the original roof, front, and back wall. Design plays a most important part in the success of the Stevens furnace.

We have frequently been asked certain questions pertaining to the regenerators, and we wish to point out that when the air supply is limited to the requirements of combustion, with all other air excluded, and the entire supply passes through the regenerators, the maximum heat recovery may be obtained if the regenerators are properly designed.

If it were possible to move the top of the regenerators to the position of the outgoing ports at the end of the hearth, a temperature approaching that of the waste gases leaving the furnace could be obtained. As this would be impractical, and as it is necessary to remove the regenerators with an intervening slag pocket and downcomers, there is, of necessity, a considerable drop in the temperature between the hearth and the top of the regenerators.

The slag pocket and downcomer expose considerable surface with a mass of brick to absorb the heat and, after adopting all practical means to prevent radiation losses, there will still remain a considerable difference in temperature between the furnace and the top of the regenerator. This top regenerator temperature places the limit upon the heat which it is possible to recover from the waste gas, and it is evident that when the required quantity of air is heated to the highest possible temperature the limit of recovery has been reached.

A definite volume or weight of air heated to a given temperature will absorb a definite quantity of heat and this quantity can not be increased, therefore, with regenerators designed to meet these conditions adequately, nothing further can be accomplished by any special design of checker or by additional checkerwork towards the stack. In the Stevens furnace the regenerators are built with standard shapes, with careful attention given to size of brick and area of space to allow free action during the long campaign. The thickness of the brick, the period of reversal, and the depth of the pass are all carefully worked out in accordance with the Stevens formula based upon reliable research data regarding the capacity and rate of transfer of heat by brick, and the results fully justify our claim that with these furnaces we obtain the highest possible thermal efficiency.

As the total heat absorbed by the gases leaving the furnace is always in excess of what it is possible to absorb by incoming air, it necessarily follows that there will be a quantity of residual heat escaping to the stack.

It is our practice to install recording pyrometers at the base of the regenerators and make continuous charts showing the temperature at this point. Records from our 100-ton basic furnace show a mean temperature during part of the heat as low as 600 degrees F., and during other periods of heat the mean temperature is approximately 800 degrees F.

Owing to the reduced temperature and reduced volume of gases passed, it becomes impractical to install waste-heat boilers in connection with the Stevens open-hearth furnace. On one occasion, before installing a Stevens furnace, we made a test of the old furnace it was to replace. We determined the temperature and volume of the waste-heat gases. When the Stevens furnace was installed we conducted similar tests and found that the B.t.u. sent to the stack by the Stevens furnace was but 17 per cent. of what we found with the old furnace which was of similar tonnage capacity.

The reactions within an open-hearth furnace are complex and it is not the present purpose to enter into a discussion of the metallurgical questions involved. We wish to say, however, that the conditions set up by the Stevens furnace have a profound effect on making and finishing a heat. This is noticeable in the reduced quantities of lime, manganese, and other additions; in the increased yield

in ingots; in the quality of slag, and the conditions of the melt and the boil, as also in the physical qualities of the steel.

Many of the ideas long held by melters must be revised. Mr. Stevens was the first to build an open-hearth furnace to operate by this method. He has done much to advance open-hearth practice, and his associates feel that he is entitled to the recognition and support of the steel industry.

Patents have been granted Mr. Stevens for his methods of construction and operation of an open-hearth furnace. The demonstrations he has made during the past four years have awakened interest and prompted others to imitate his method in part, but the results are far short of what is accomplished in the Stevens furnace for the reason that this furnace is built to meet all the requirements of the methods used, and is a complete grouping of all contributing factors, to make the most efficient unit.

DISCUSSION

BARTON R. SHOVER, *Chairman:** Some of the audience have seen the furnace and know what it has done. Others may wish to have further information or to question some of the statements, and it is hoped that there will be no hesitation in doing so.

About three years ago I saw heat No. 206 made on the Indiana Harbor furnace. At this time the brickwork of the furnace gave no evidence of having been used, except two comparatively small places where about one-half inch had spalled off the brick. The paint on the plate covering the back wall was intact and a few streams of slag had run down the walls of the downtake. The statement was made that absolutely no repairs of any kind had been made to the furnace up to that time. There was practically no variation in the stack draft which was automatically controlled and the temperature of the outgoing gases was practically constant. Stack-gas analysis over a good portion of the run showed less than one per cent. free oxygen except in a few cases where the notation stated that the doors were open or some other occurrence allowed the infiltration of air. The management stated that the furnace and its product were both superior to anything that had ever been experienced with their other furnaces.

*Consulting Engineer, Pittsburgh.

Pig-iron in the charge had been reduced from 25 per cent. to 15 per cent. Sprues and risers had been reduced 25 per cent. in weight, casting-floor charges including welding had dropped 20 per cent., and the gross fuel consumption decreased from 45 to a trifle over twenty-three gallons of oil per net ton of castings.

W. P. CHANDLER:* Are you speaking of an acid furnace?

BARTON R. SHOVER: That was an acid furnace.

W. P. CHANDLER: The speaker was speaking of a basic furnace.

THOMAS G. KUS: I was speaking of a 30-ton acid furnace and also of a 100-ton basic furnace.

BARTON R. SHOVER: The 30-ton acid furnace was the first one built. I wonder if Mr. Chandler would add anything.

W. P. CHANDLER: I have had no experience at all with the Stevens furnace. From the accounts that have been given it seems to be a very well constructed and well operated furnace.

W. N. FLANAGAN:† I feel somewhat like Mr. Chandler, I never had the privilege of seeing the Stevens furnace. The speaker to-night outlined the ideal workings of an open-hearth furnace which we are all striving after in designing. However, it would have been of very great interest had he introduced some sketches or drawings or an outline of the principal features wherein the design of the Stevens furnace differs from the ordinary run of furnaces, particularly those features which led to better than ordinary results.

THOMAS G. KUS: There are certain fundamental physical laws that no one can alter. We have adhered to the fundamentals involved in designing these furnaces. As outlined in the paper, we aim at (1) the introduction into the furnace of the exact quantities of fuel and air required for perfect combustion; (2) the exclusion of all infiltered air; and (3) the maximum heat recovery in regenerators.

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†Special Engineer, Carnegie Steel Co., Pittsburgh.

The various features of design, such as plating of the furnace, the elimination of openings around doors and burners, and the correct proportioning of regenerators, are merely the practical means towards ideal results. That we have approached very closely to ideal results is evidenced by records. The 100-ton basic furnace shows routine repair cost of 7.4 cents, including a 35 per cent. overhead. During one month it ran 6629 tons, or 23½ gallons per gross ton of ingots. The average was 9¼ tons an hour. Furthermore, the additions to the 100-ton charge in the Stevens furnace were practically the same in quantity as the additions used for 80-ton charge with old furnaces at the same plant.

The point regarding heat recovery may be illustrated by records taken in the regenerators. We took top temperatures every 20 minutes for four days and we found that the highest temperatures on top of the regenerators were 2330 degrees. We also found a drop of only 148 degrees during the reversal period.

J. M. HUGHES:* Was that 9¼ tons to tap or charge?

THOMAS G. KUS: The average per hour for the month.

J. M. HUGHES: Wasn't considerable of the reduction in pig-iron due to the burned lime?

THOMAS G. KUS: No, I do not think it was; I think it was due chiefly to the furnace atmosphere. We started a 30-ton basic furnace last month. That was another place where they were very particular about their charge. They know just what scrap they are putting in and everything about it. When starting up they charged as usual for their old furnaces, and melted down very high in carbon, taking several hours to come down to requirements. Of course, that was remedied by cutting the quantity of pig-iron in the charge. A reduction in the quantity of manganese was also effected.

J. M. HUGHES: Was that a low or high carbon?

THOMAS G. KUS: That was 0.26-0.30 per cent. carbon.

*Superintendent, Sharon Steel Hoop Co., Lowellville, Ohio.

J. W. Kinnear, Jr.:* How do you vary your air for your ore and lime reaction?

Thomas G. Kus: The air is proportioned for perfect combustion of the fuel, and is not changed during the heat.

J. W. Kinnear, Jr.: Do you get perfect combustion when there is no fuel reaction?

Thomas G. Kus: Yes, in practically neutral atmosphere, with flue-gas analysis showing slightly more CO_2 and traces of CO during gasification.

J. W. Kinnear, Jr.: What is the draft in the hearth?

Thomas G. Kus: Practically at atmospheric pressure.

J. W. Kinnear, Jr.: Is that with the stack damper closed?

Thomas G. Kus: No; with the stack damper opened just enough to maintain proper draft condition.

J. W. Kinnear, Jr.: How do you take the preheat in the checkers?

Thomas G. Kus: It was taken every 20 minutes for four days with an optical pyrometer.

J. W. Kinnear, Jr.: That was the surface of the brick?

Thomas G. Kus: Yes. We had no thermo-couples.

E. A. Brown:† The information which Mr. Kus has given us has proved so interesting and the fuel figures so remarkably low that I would like to verify several points. I understand that he reported

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†Assistant to Chief Mechanical Engineer, Homestead Works, Carnegie Steel Co., Munhall, Pa.

a fuel consumption of 3,500,000 B.t.u. per ton of product. Was this figure based on higher or lower heating values?

THOMAS G. KUS: The low values.

E. A. BROWN: Does the fuel figure reported represent short-time tests for actual operating periods, or does it include idle week-end gas?

THOMAS G. KUS: It is a monthly figure, including stand over.

E. A. BROWN: Is the fuel based on gross or net tons?

THOMAS G. KUS: It represents the gross ton of ingots.

E. A. BROWN: Could you make an estimate of what the CO_2 or oxygen excess would average over an entire heat as sampled at the base of the stack? I would like to hear this figure as a measurement of total air infiltration for the entire furnace system.

THOMAS G. KUS: I have no figures. Our operation ends at the base of the regenerators.

E. A. BROWN: Do you have any results of analyses as leaving the regenerators?

THOMAS G. KUS: It is virtually the same in the downtakes where samples are taken. There is no appreciable infiltration of air after passing that point. The CO_2 would average 14.9 to 15.9 per cent.

E. A. BROWN: What percentage of pig-iron is represented by the period over which the 3,500,000 B.t.u. consumption was obtained?

THOMAS G. KUS: That would, of course, depend on the required carbon content of the finished steel. For 0.08 to 0.12 carbon, about thirty per cent. of pig-iron would be used; for 0.48 to 0.52 carbon, about thirty-six per cent.; and for 0.95 to 1 carbon, thirty-nine per cent.

E. A. Brown: Did I understand that the brickwork of the furnace proper was laid tight in cement, or only some special parts?

Thomas G. Kus: We used cement around the burner block, but the other brickwork was laid up loose. It has to be, in a rigid steel construction.

J. D. Keller:* You stated that the heat losses from the downtakes and slag pockets were reduced to the greatest practicable extent. Was this done by additional insulation?

Thomas G. Kus: No. The idea I intended to convey is that these unavoidable losses are minimized by bringing the checkers as close as is practicable to the outgoing gas-ports in the furnace chamber. Insulation is provided around slag pockets up to about the level of the charging floor.

J. D. Keller: Do you use any special quality of refractory back of the insulation?

Thomas G. Kus: No.

H. J. Williams:† Did you use a mushroom-type reversing valve in this furnace?

Thomas G. Kus: No, we used a Stevens valve which is a rotary sliding type.

H. J. Williams: In regard to the regenerator chambers, do you have four inches of insulation between the brickwork and the steel casing?

Thomas G. Kus: Four inches of insulation and then casing.

H. J. Williams: What is the size of the vertical flues in the regenerator chambers?

*Mechanical Engineer, Carnegie Institute of Technology, Pittsburgh.
†Salesman, Equitable Gas Co., Pittsburgh.

THOMAS G. KUS: That depends on the size of the furnace, and somewhat on the limitations of construction.

H. J. WILLIAMS: In your experience with the Stevens open-hearth furnace have you noticed that, when a furnace is near the end of its run, the temperature of the waste gases in the flues between the checker chamber and the reversing valve is much higher than the temperature taken in the same place on the same furnace during the early part of its run?

THOMAS G. KUS: It does not show any difference.

H. J. WILLIAMS: I mention this because I have had some experience with temperature recording in the flues at the base of the checker chambers and I found that, towards the end of the run, the average waste-gas temperature was very much higher than it was during the early part of the run. This was probably due to the checkerwork being burned out. I just wondered if you had noticed this in a Stevens furnace after it had been in operation for a long time.

THOMAS G. KUS: We have not noticed it.

H. J. WILLIAMS: Are all the furnaces you have built to date fired by fuel-oil?

THOMAS G. KUS: It just happens so, unfortunately.

H. J. WILLIAMS: If you were building a furnace for natural gas would you put the gas-burners in through the sides of the ports or in through the end walls?

THOMAS G. KUS: The end of the furnace.

H. J. WILLIAMS: I see. You would put the gas-burners in the same place you put the oil-burners.

THOMAS G. KUS: Yes.

H. J. Williams: Do the burners extend into the furnace beyond the end walls over the top of the center uptake?

Thomas G. Kus: In a 30-ton furnace, they go in 18 inches.

H. J. Williams: I understand that the 30-ton furnace produced four heats every day.

Thomas G. Kus: Yes; that was the foundry schedule.

H. J. Williams: In your opinion, if this furnace had been fired by natural gas would it have produced heats as rapidly?

Thomas G. Kus: Yes.

H. J. Williams: Do you reverse the furnace according to time or according to the temperature of the waste gases?

Thomas G. Kus: According to time.

H. J. Williams: Then the melter does not look at the chart or temperature indicating lights on the recording pyrometer in order to see when he should reverse the furnace?

Thomas G. Kus: No.

H. J. Williams: Do you have automatic means for regulating and proportioning the flow of oil and air at all stages of turn down, or is that manually controlled by the melter with the aid of indicating flow meters on the oil and air lines?

Thomas G. Kus: It is automatic. When starting a furnace we make an arbitrary setting, make a flue-gas analysis, and, if it indicates an excess of either fuel or air, we make adjustments until we get the correct composition of flue-gas. The regulator is then set, and remains that way. The proportion is the same, no matter how much fuel is used.

STRUCTURAL ANALYSIS BASED ON THE MOMENT DISTRIBUTION METHOD OF CROSS*

By T. D. Mylrea†

In the *Proceedings of the American Society of Civil Engineers* (May 1930, volume 56, page 919) appears an article by Professor Hardy Cross, with discussion, on "Analysis of Continuous Frames by Distributing Fixed-End Moments." Believing that the method possesses great merit and yet that it may be overlooked by the very men it was intended to reach, the practising designers, the writer ventures in the following pages to call it to their attention by means of problems worked out to show its application. Every step has been explicitly pointed out, which makes some of the explanations lengthy, and it is hoped that the reader does not thereby get the impression that the method is involved. Certain fundamental relations are first developed, Cross's method of using them being brought out later.

Referring to Fig. 1(*a*), if a moment M be applied at one end of a simple beam of length l, the reactions and moment diagram are as shown. Similarly, if a moment m be applied at the other end, Fig. 1(*b*) shows the effect. If moments be applied at both ends simultaneously then the resulting reactions, shown in Fig. 1(*c*), will be the algebraic sum of those in Fig. 1(*a*) and 1(*b*), and the combined moment diagram will be a trapezoid. These diagrams illustrate the effect of restraint of any degree at either end or both ends of an otherwise simple beam.

For example, the beam of Fig. 1(*d*), carrying a load P and restrained at both ends, may be represented by the simple beam of Fig. 1(*e*) subjected to the additional effects of the moments (as yet unknown) of Fig. 1(*f*). The corresponding moment diagrams are shown in Fig. 1(*g*), 1(*h*), and 1(*i*), the triangular positive moment diagram being superimposed upon the trapezoidal negative moment diagram, using as a base the line de. The restraint may be due to a built-in condition of the ends or to continuity with an adjoining column or beam span. Since a continuous beam is merely a series of

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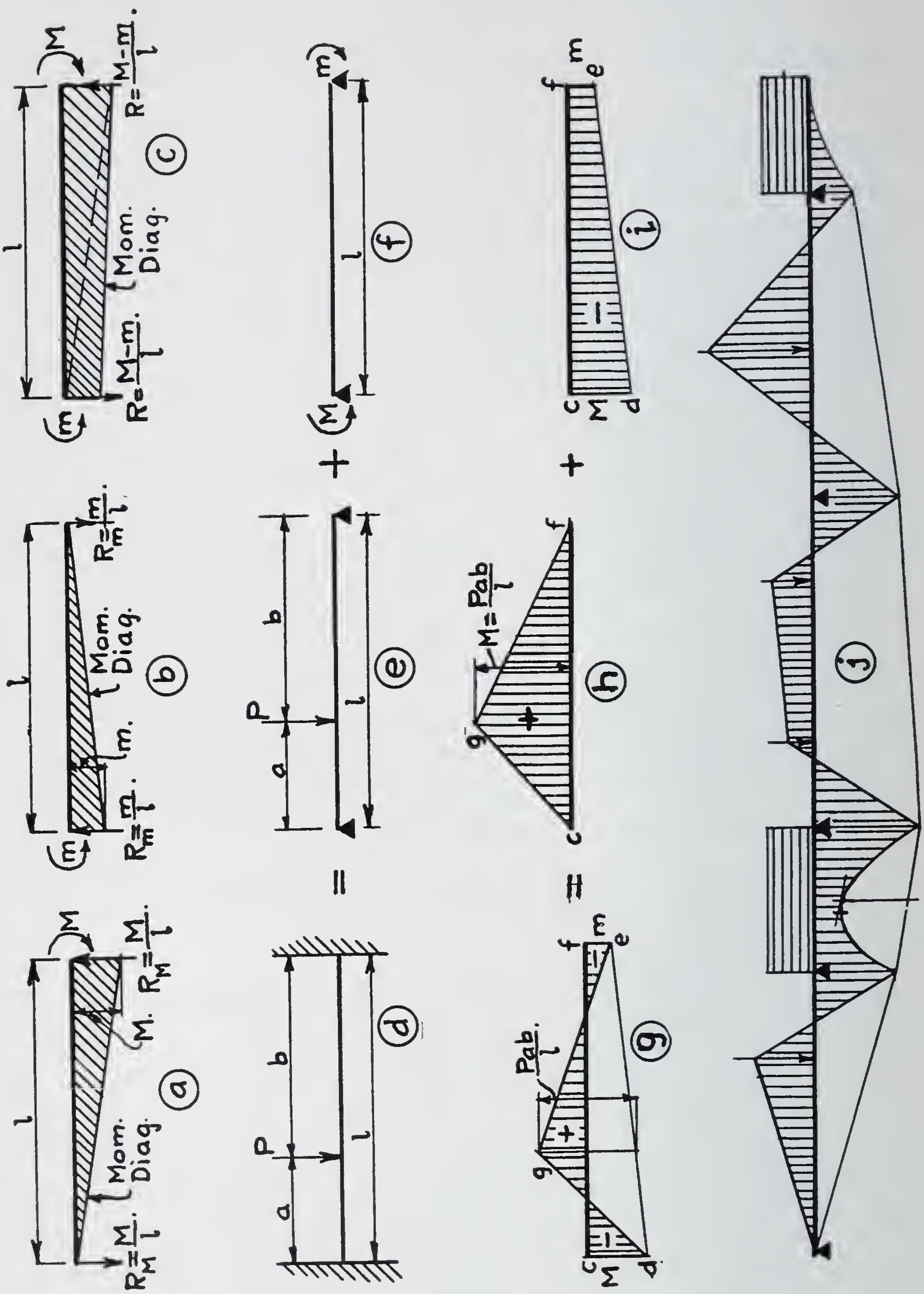


Fig. 1

such beams, end to end, the construction of the moment diagram for a continuous beam becomes a simple matter when once the negative moments over the supports are known. These moments are laid off vertically below their respective supports, a base-line is drawn as in Fig. 1 (j), and the ordinates of the simple-beam moment diagram for each span plotted vertically from this base.

The problem of continuity is, then, primarily one of finding the moments at the supports. The classical three-moment equation is familiar to every designer; some prefer the slope-deflection method of Maney and Wilson; and many are adept with the "fixed-point" graphical constructions originated by Claxton-Fidler* and elaborated by Ostenfeld,† Nishkian and Steinman,‡ and others. Cross's method is a rapidly converging series of successive approximations, which may be carried to any desired degree of precision. It may be summarized as follows. Each span is first considered as fixed at both ends; that is, forced to maintain, after loading, the slope over each support that it had before loading. The end moments due to the applied loads are now computed. Then the restraint at one support is removed; and if the moments on the adjoining sides of this support differ, the beam assumes a new slope at this support and the difference in moment is divided between the adjoining beams in proportion to their stiffness. The unbalanced moment having been distributed, the beam is again fixed in its new position at this support and the unbalanced moment at the next support distributed. This process is continued for each support. The balancing at one support may throw out of balance another which has previously been balanced, in which event the process is repeated until no finer adjustment is considered necessary. Before proceeding with illustrative examples it will be well to discuss, first, a short method for determining fixed-end moments, and, second, a method of determining the relative stiffness of beams.

In finding the fixed-end moments, the area moment theorems of Greene and Mohr are very convenient. Any other method with which the designer is familiar will, of course, answer just as well. Texts on strength of materials develop the following formulæ for slope and deflection:

*"Practical Treatise on Bridge-Construction," by Thomas Claxton-Fidler. Ed. 2, 1893. (Chapter 9.)

†"Teknisk Statik," by A. Ostenfeld. Ed. 2, v. 2, 1913.

‡*Trans. A. S. C. E.*, 1927, v. 90, p. 1.

$$\theta = \int_A^B \frac{Mdx}{EI}, \text{ and } \triangle = \int_A^B \frac{Mdx}{EI} x.$$

From Fig. 2(a), these formulæ may be expressed as follows:

$\theta = \int_A^B \frac{Mdx}{EI} = \frac{1}{EI}$ (Area of the moment diagram between A and B) ....theorem 1

$\triangle = \int_A^B \frac{Mdx}{EI} x = \frac{1}{EI}$ (Moment of the area of the moment diagram between A and B about point B.)

$= \frac{1}{EI}$ (Area of the moment diagram between A and B multiplied by the distance from its center of gravity to point B)......theorem 2

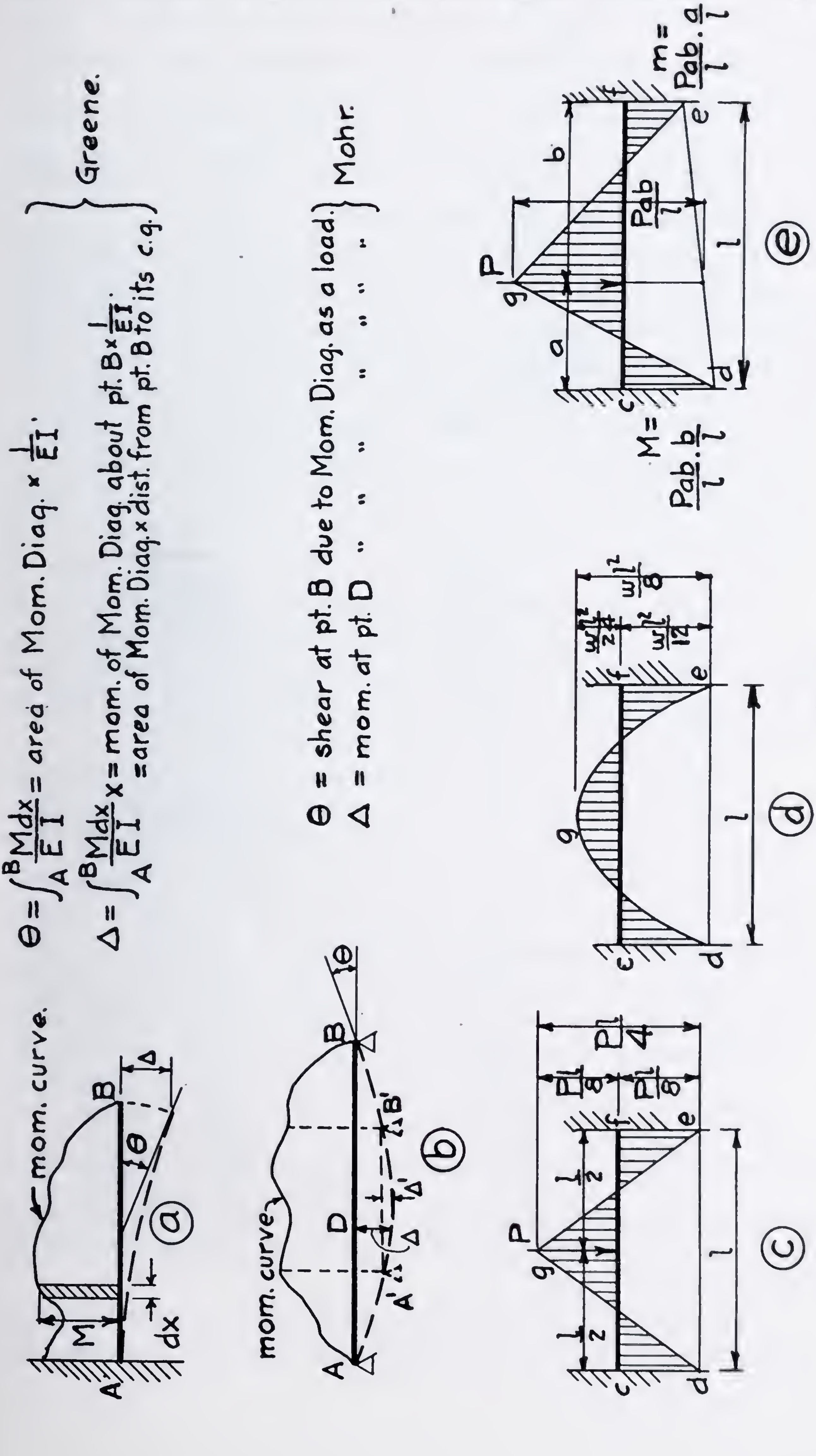
These are usually referred to as Greene's theorems. Since points A and B may be anywhere on the beam, theorem 2 refers to the deflection of point B away from the tangent at point A and at right angles to this tangent. Also, if I varies along the beam, then theorems 1 and 2 may be expressed in terms of $\frac{1}{E}$ and the area of the $\frac{M}{I}$ diagram.

Similarly, but without proof, referring to Fig. 2(b), Mohr's theorems may be expressed as follows:

$\theta_B = \frac{1}{EI}$ (Shear at B due to moment diagram considered as a load) .... theorem 3

$\triangle_D = \frac{1}{EI}$ (Moment at D due to moment diagram considered as a load)..theorem 4

These slopes and deflections are measured with reference to a line joining reactions, real or imaginary. Thus the slope at B^1 with reference to the line joining A^1 and B^1 is $\frac{1}{EI}$ times the shear at B^1 due to that portion of the moment diagram shown which lies between points A^1 and B^1 when this portion is considered as a load on span A^1B^1. As with Greene's theorems, variations in I may be taken care



Θ = ∫ from A to B of Mdx/EI = area of Mom. Diag. × 1/EI
Δ = ∫ from A to B of Mdx/EI x = mom. of Mom. Diag. about pt. B × 1/EI
= area of Mom. Diag. × dist. from pt. B to its c.g.
Greene.
Θ = shear at pt. B due to Mom. Diag. as a load.
Δ = mom. at pt. D " " " " "
Mohr.
mom. curve.
A
M
dx
Θ
B
Δ
(a)
mom. curve
D
A'
B'
Δ'
(b)
P
g
c
d
e
f
l/2
l
Pl/8
Pl/4
(c)
wl²/24
wl²/12
wl²/8
(d)
a
b
Pab/l
M = Pab/l · b/l
m = Pab/l · a/l
(e)

Fig. 2

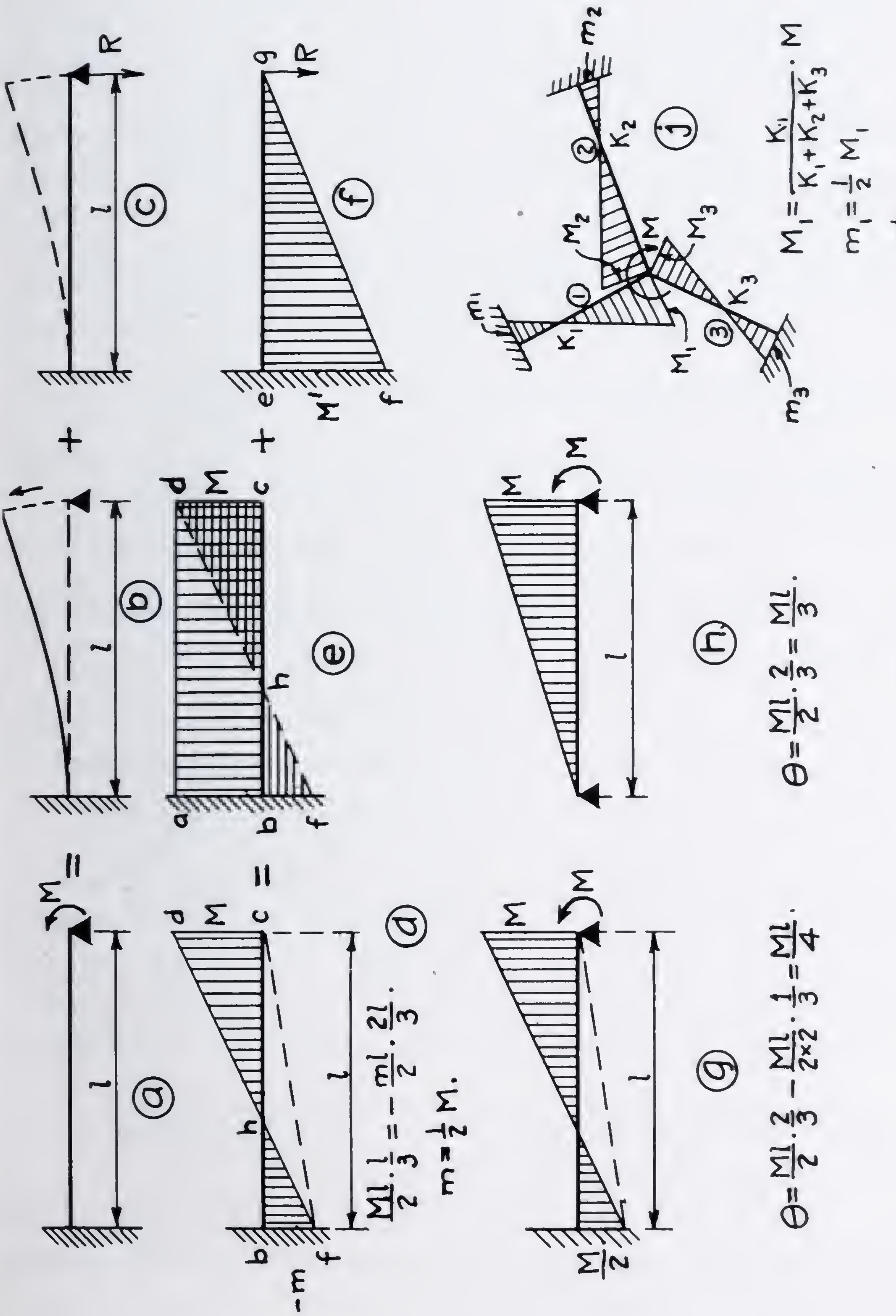
of by the use of the $\frac{M}{I}$ diagram. In the remainder of this discussion E will be considered constant, I will be regarded as constant in any one span, and since in most equations the term $\frac{1}{EI}$ appears on both sides it will be omitted unless its use is essential.

Let the beam of Fig. 2(*c*), fixed at both ends, be loaded with a single concentrated load, P, at midspan. The triangle gde is the simple-beam, positive, moment diagram and the rectangle cdef is the negative moment diagram due to the fixed condition of the ends. We know that there is no change of slope in the tangent at c relative to the tangent at f. Hence, from theorem 1, the total area of the moment diagram between these two points must be zero; that is, the areas of the positive and negative moment diagrams must be equal, which can occur only when line cf is one-half the height of the triangle above line de.

Similarly, for a uniformly loaded beam having fixed ends, as shown in Fig. 2(*d*), the area under the parabola gde must equal the area of the rectangle cdef. Since the area under a parabolic segment is two-thirds the area of the inclosing rectangle, the line cf must be two-thirds the height of the parabola above line de.

If a single concentrated load be applied unsymmetrically to a beam having fixed ends, conditions will be as illustrated by Fig. 2(*e*). Since there is no change of slope in the tangent at c relative to the tangent at f, the areas of the positive triangle and negative trapezoid are equal. Also, from theorem 2, since point f does not deflect with relation to the tangent at c, the moment about f of the triangle must equal the moment of the trapezoid about the same point. The triangular and trapezoidal areas being equal and having the same moment about a common point, their centers of gravity must be at the same distance from f. From these two relations the values $M = \frac{Pab}{l} \times \frac{b}{l}$ and $m = \frac{Pab}{l} \times \frac{a}{l}$ are easily determined, and these are simple fractions of the simple-beam moment. For any combination of uniform and concentrated loads it is only necessary to compute the separate end moments and add.

The stiffness of a beam may be defined as its resistance to angular distortion at the end under consideration, and may be expressed as



(a) (b) (c) (d) (e) (f) (g) (h) (j)
$\frac{Ml}{2}\cdot\frac{l}{3}=-\frac{ml}{2}\cdot\frac{2l}{3}$.
$m=\frac{1}{2}M$.
$\theta=\frac{Ml}{2}\cdot\frac{2}{3}-\frac{Ml}{2\times 2}\cdot\frac{1}{3}=\frac{Ml}{4}$.
$\theta=\frac{Ml}{2}\cdot\frac{2}{3}=\frac{Ml}{3}$.
$M_1=\frac{K_1}{K_1+K_2+K_3}\cdot M$
$m_1=\frac{1}{2}M_1$
etc.

Fig. 3

the reciprocal of the flexibility or angular rotation at this end. Consider the beam of Fig. 3(*a*), fixed at one end and subjected to a moment, M, at the other. If the unrestrained end is not anchored down, the beam will curve upward as shown in Fig. 3(*b*), giving the rectangular moment diagram abcd of Fig. 3(*e*). Since the end must not lift, a downward reaction, R, Fig. 3(*c*), is developed, giving rise to a negative moment diagram efg, Fig. 3(*f*). The magnitude of R and of the ordinate ef may be determined by means of theorem 2 from the fact that the deflection of the right end of the beam away from the tangent at the left end is zero; that is, the upward deflection of the right end in Fig. 3(*b*) is equal to the downward deflection in Fig. 3(*c*). Hence $M \times l \times \frac{l}{2} = M^1 \times \frac{l}{2} \times \frac{2}{3} l$, or $M^1 = \frac{3}{2} M$.

If the two diagrams be superimposed, as in Fig. 3(*e*), line eg coinciding with line ad, point f will fall below point b, and the distance bf will equal $\frac{1}{2}$ ab. The resultant moment diagram bfhdc is shaded horizontally, area abhd mutually canceling out. The fact that ordinate bf $= \frac{1}{2}$ ordinate dc may be checked as in Fig. 3(*d*) by means of theorem 2. The right end of the beam does not deflect with reference to the tangent at the left end. Therefore the moment of the moment diagram about the right end equals zero, or the moment of the positive diagram equals the moment of the negative diagram. For convenience, the shaded moment diagram may be thought of as being comprised of the positive diagram fdc and the negative diagram cbf, the area fhc mutually canceling. Then $\frac{Ml}{2} \times \frac{l}{3} = -\frac{ml}{2} \times \frac{2l}{3}$, and

$$m = -\frac{M}{2} \quad \text{(equation 1)}$$

In Cross's terminology this $m = -\frac{1}{2} M$ is called the "carry over" moment. Its use will be apparent later.

The rotation of the right end under the influence of the moment M may be found, as in Fig. 3(*g*), by the application of either theorem 1 or theorem 3. Selecting theorem 3, at the right end:

$$\theta = \frac{1}{EI} \times M \frac{l}{2} \times \frac{2}{3} - \frac{M}{2} \times \frac{l}{2} \times \frac{1}{3} = \frac{Ml}{4EI} \quad \text{(equation 2)}$$

This may be conceived as a measure of the flexibility of the beam when the "far" end is fixed. It will be useful to compare this with the flexibility when the far end is free. Consider, then, in Fig. 3(h), the same beam with the left end free. The moment diagram is as shown, and $\theta = \frac{1}{EI} \times M\frac{l}{2} \times \frac{2}{3} = \frac{Ml}{3EI}$ ....(equation 3)

There is, of course, no "carry over" moment to the free far end of a beam.

From equations 2 and 3 it is apparent that the flexibility of any beam is proportional to its $\frac{l}{I}$, or its stiffness is proportional to its $\frac{I}{l}$. Since in all problems of continuity, beams are regarded from the standpoint of stiffness, rather than flexibility, their $\frac{I}{l}$ values become significant, and it is customary to designate the $\frac{I}{l}$ value of any beam by the symbol K. The values of K may be the actual values of $\frac{I}{l}$, or more conveniently, simple numbers proportional thereto, since relative values only are needed.

Equation 2 might be rewritten, $\theta = \frac{1}{4E} \times \frac{M}{K}$, or

$M = K\,\theta\,4E$ ....(equation 4)

In the above it is seen that, θ and E being constant, M varies directly with K. It is evident, therefore, that if the corresponding ends of a number of similar beams having different stiffness or K values are forcibly rotated through the same angle, the moments required to produce these rotations will be in proportion to the K values of the several beams.

Comparing equations 2 and 3 shows that, under the influence of a moment at one end, a beam free at the far end is $\frac{4}{3}$ as flexible or $\frac{3}{4}$ as stiff as when fixed at the far end, and hence only $\frac{3}{4}$ as great a moment will be required to rotate it through the same angle; that is, the moment required will be the same as that required to rotate the end of a beam, fixed at the far end, which

has an $\frac{I}{l}$ value only $\frac{3}{4}$ that of the free-ended beam. Therefore, if a beam free at the "far" end is to be treated in combination with beams with fixed far ends, its $\frac{I}{l}$ value should be multiplied by $\frac{3}{4}$ to give comparable K values, or else the K values of all the fixed-end beams should be multiplied by $\frac{4}{3}$. It is more convenient to fix on the uniform practice, say, of multiplying the $\frac{I}{l}$ values of all such free-end beams by $\frac{3}{4}$. If all the beams of a group are free ended, no such adjustment is necessary, since the rotations of all are comparable.

When several members meet in a joint, and the joint is forcibly rotated, it is assumed that although the members themselves are bent by the rotation, the angles between the tangents to the members at the joint remain unchanged. Hence, under the influence of a moment M, Fig. 3(j), the ends of the members 1, 2, and 3 meeting at the joint are rotated through the same angle, and it follows that the resisting moments developed, M_1, M_2, and M_3 will be proportional to K_1, K_2, and K_3. That is, if $K_1 = 8$, $K_2 = 4$, and $K_3 = 12$, then $M_1 = \frac{8}{24} M$, $M_2 = \frac{4}{24} M$, and $M_3 = \frac{12}{24} M$; the "carry over" moments will be one-half as great. If the far end of any of these members, say member 3, were free, the K value of that member would be modified thus: $K_3 = \frac{3}{4} \times 12 = 9$. Then $M_1 = \frac{8}{21} M$, $M_2 = \frac{4}{21} M$, and $M_3 = \frac{9}{21} M$, and the "carry over" moments in members 1 and 2 would be $\frac{4}{21} M$ and $\frac{2}{21} M$, respectively.

Cross's method is based upon the fundamentals so far developed.

1. Members meeting in a joint rotate through equal angles at the joint.

2. A moment applied at a joint is divided between the members in proportion to their K values, which depend upon the $\frac{I}{l}$ values of the members and the degree of fixity at the far ends.

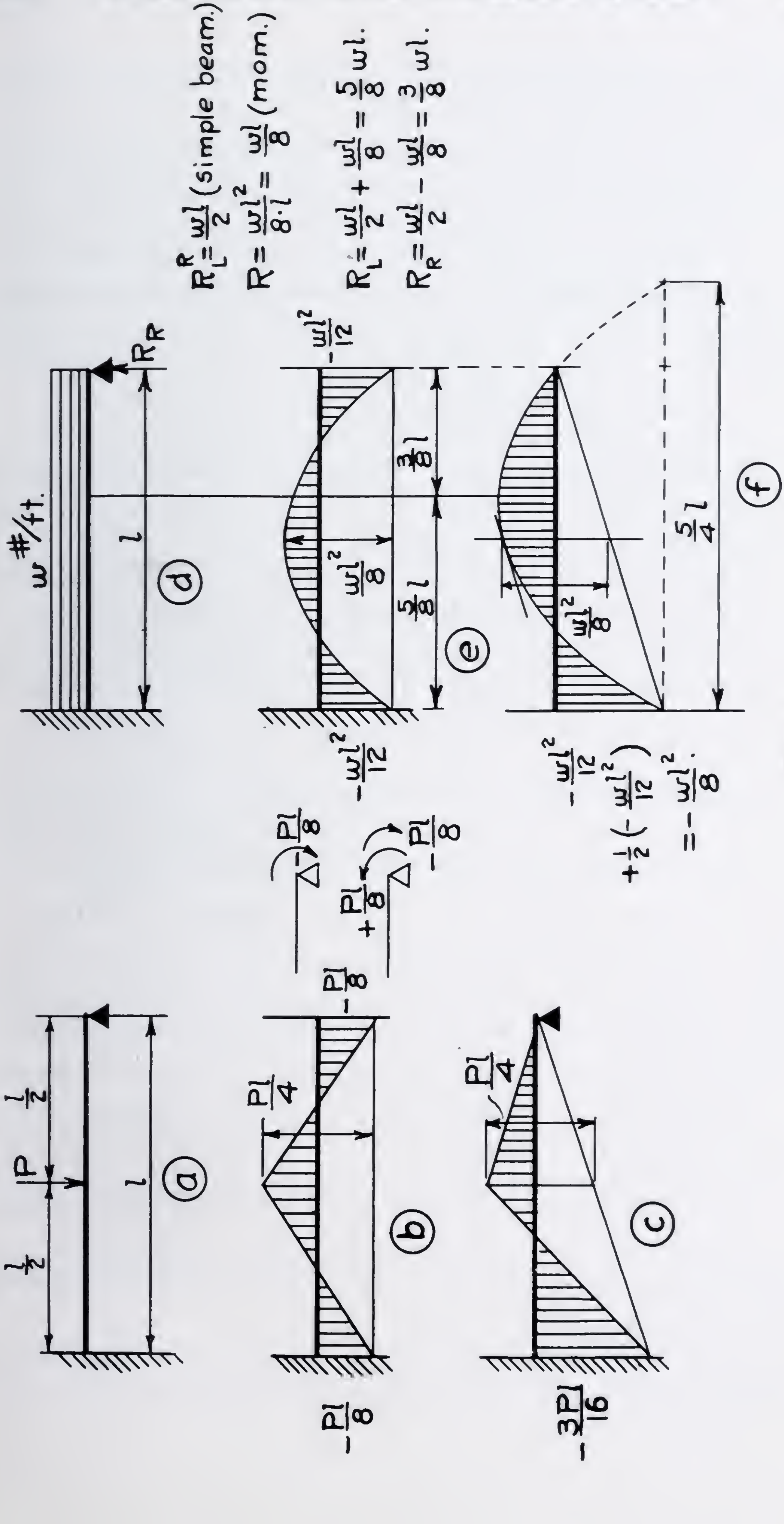

R_L^R = wl/2 (simple beam.)
R = wl²/8·l = wl/8 (mom.)
R_L = wl/2 + wl/8 = 5/8 wl.
R_R = wl/2 − wl/8 = 3/8 wl.
w #/ft.
R_R
l
d
wl²/8
−wl²/12
5/8 l
3/8 l
e
5/4 l
f
−wl²/12
+1/2(−wl²/12)
= −wl²/8.
P
l/2
l
a
Pl/4
−Pl/8
b
c
−3Pl/16

Fig. 4

3. A member free at the far end has a K value $\frac{3}{4}$ as great as a like member fixed at the far end.

4. If a moment, M, is applied to a member the far end of which is fixed, a moment of $\frac{1}{2}M$ is "carried over" to the fixed end.

A very engaging field of approximate analysis is opened to view by paragraphs 3 and 4 above, since the K value of a member must lie between $\frac{I}{l}$ and $\frac{3}{4}\frac{I}{l}$, and, therefore, the "carry over" moment can not exceed $\frac{1}{2}$ M; but we must not pause to digress.

As the first example of the application of the method consider the beam of Fig. 4(a), fixed at one end, supported at the other, and carrying the load P at midspan. The weight of the beam is neglected, but can be included, if desired, as shown in the example for uniform load. Before applying the load, let the beam be temporarily fixed or locked against rotation at the right end. The moments produced by the load are those of Fig. 4(b), a negative resisting moment of $-\frac{Pl}{8}$ being required of the lock on the right-hand end, as illustrated by the upper thumb-nail sketch. (See also Fig. 2(c). If now the lock be released, the moment at the right-hand end will become zero; the effect being exactly the same as if a positive counter moment of $+\frac{Pl}{8}$ were applied to the lock, as shown in the lower thumb-nail sketch. This counter moment, $+\frac{Pl}{8}$, applied at the right end will reduce the moment of $-\frac{Pl}{8}$ at the right end of Fig. 4(b) to zero, but a "carry over" moment of $-\frac{1}{2}\left(+\frac{Pl}{8}\right)=-\frac{Pl}{16}$ will appear at the left end in addition to the $-\frac{Pl}{8}$ already there, the two together forming a final negative moment of $-\frac{3Pl}{16}$ at this point. The complete moment diagram is drawn as in Fig 4(c).

After the principle is grasped, it is usually unnecessary to go through all the steps above. It is generally sufficient to shorten the

work to some such statement as, "The negative moment at the right end is released and half of it 'goes over' to the left end."

A similar beam with a uniform load would be treated as in Fig. 4(*d*), 4(*e*), and 4(*f*). The moment at the right end, when this end is temporarily locked, is $-\frac{wl^2}{12}$. When "released," $-\frac{wl^2}{24}$ "goes over" to the left end, and the diagram is modified as in Fig. 4(*f*). The height of the simple beam part of the latter diagram at midspan is still $\frac{wl^2}{8}$, the curve at this point being tangent to a line drawn parallel to the sloping base-line. The maximum positive ordinate is to the right of the midspan, and its position may be determined by first finding the reactions. From the load alone, both ends being considered free, R_R and R_L each equals $\frac{wl}{2}$. From the moment at the left end—See Fig. 1(*b*)—R_L and R_R each $= \frac{wl^2}{8 \times l} = \frac{wl}{8}$, acting upwards at the left-hand support and downwards at the right. The combined reactions, then, are $R_L = \frac{wl}{2} + \frac{wl}{8} = \frac{5}{8}\,wl$, and $R_R = \frac{wl}{2} - \frac{wl}{8} = \frac{3}{8}\,wl$. The point of zero shear or maximum moment is, therefore, $\frac{3}{8}\,l$ from the right-hand support. The rest is a matter of statics.

Fig. 5 represents a two-span beam, fixed at both ends, with a single concentrated load off center in one span. For convenience the spans have been made identical, so K for each span may be considered equal to unity. First lock both spans at the middle support. The end moments in the right-hand span are then —16,000 and —8000 as shown in line a, and are computed as in Fig. 2(*e*). The shape of the deflected beam is shown as a full line in Fig. 5(*c*). Releasing the lock at the middle support is equivalent to applying a counter moment of 16,000 to the condition already existing there. If there were no left-hand span this would reduce the moment to zero at this support. But the applied moment expends itself in bending both spans to the shape given in the dotted line of Fig. 5(*c*). Thus half the effort "goes to" each side of the support (since K for both

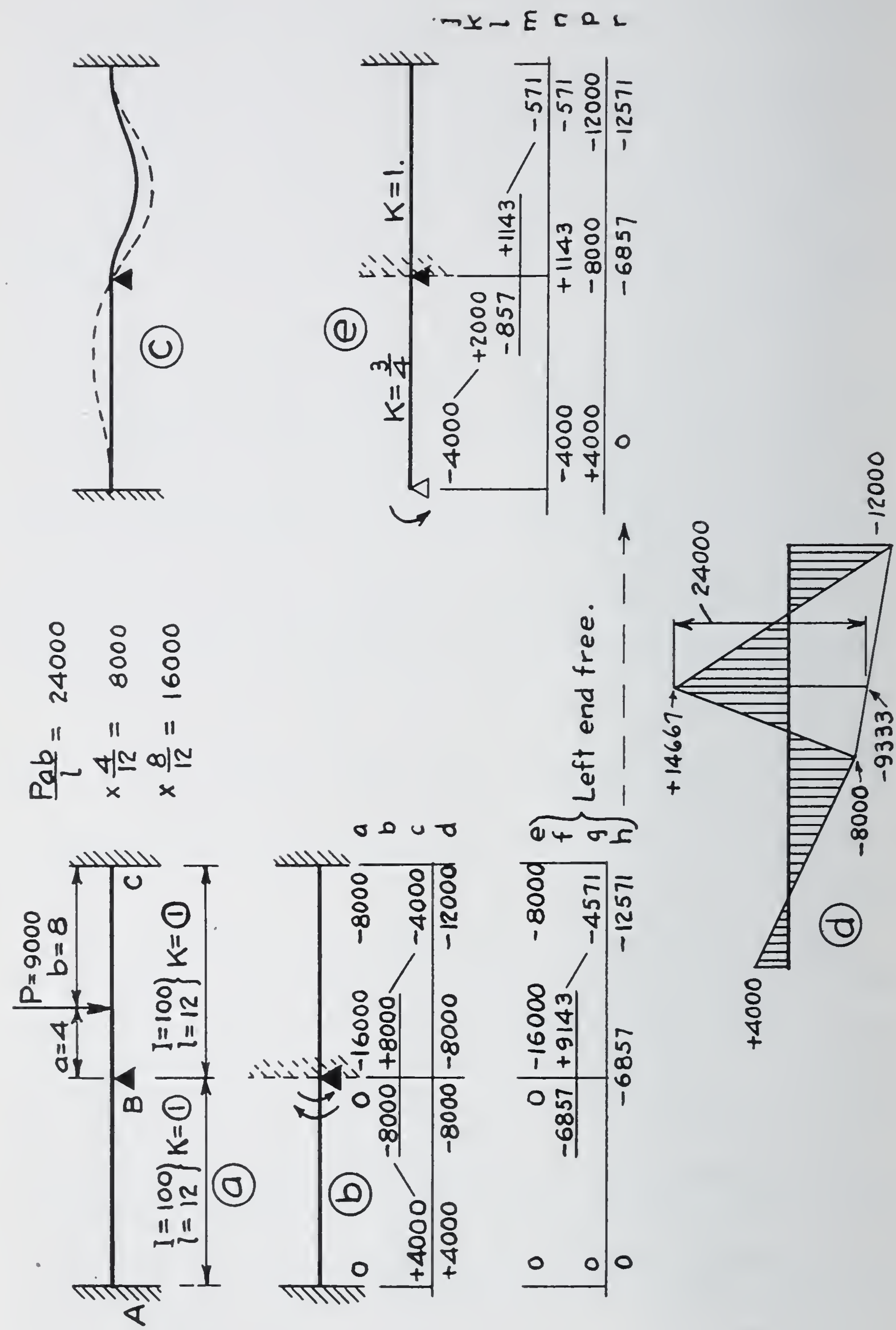

P=9000
a=4
b=8
A
B
C
I=100
l=12
K=①
$\frac{Pab}{l}$ = 24000
× $\frac{4}{12}$ = 8000
× $\frac{8}{12}$ = 16000
Left end free.
K=$\frac{3}{4}$
K=1.
+14667
24000
-12000
+4000
-8000
-9333
-6857
-12571
+1143
-571
+2000
-857
-4000
+4000
0
a
b
c
d
e
f
g
h
j
k
l
m
n
p
r

Fig. 5

sides is the same), reducing the moment on one side of the support and inducing a moment in the beam on the other side. This reducing moment and induced moment are shown in line b, and from each of these moments there is a "carry over" moment of 4000 to the fixed ends, as shown in line c. The beam is now in a state of rest with no new moments appearing at the middle support, so the final moments at all supports are obtained by the addition of lines a, b, and c, giving the values of line d. The final moment diagram is shown in Fig. 5(*d*).

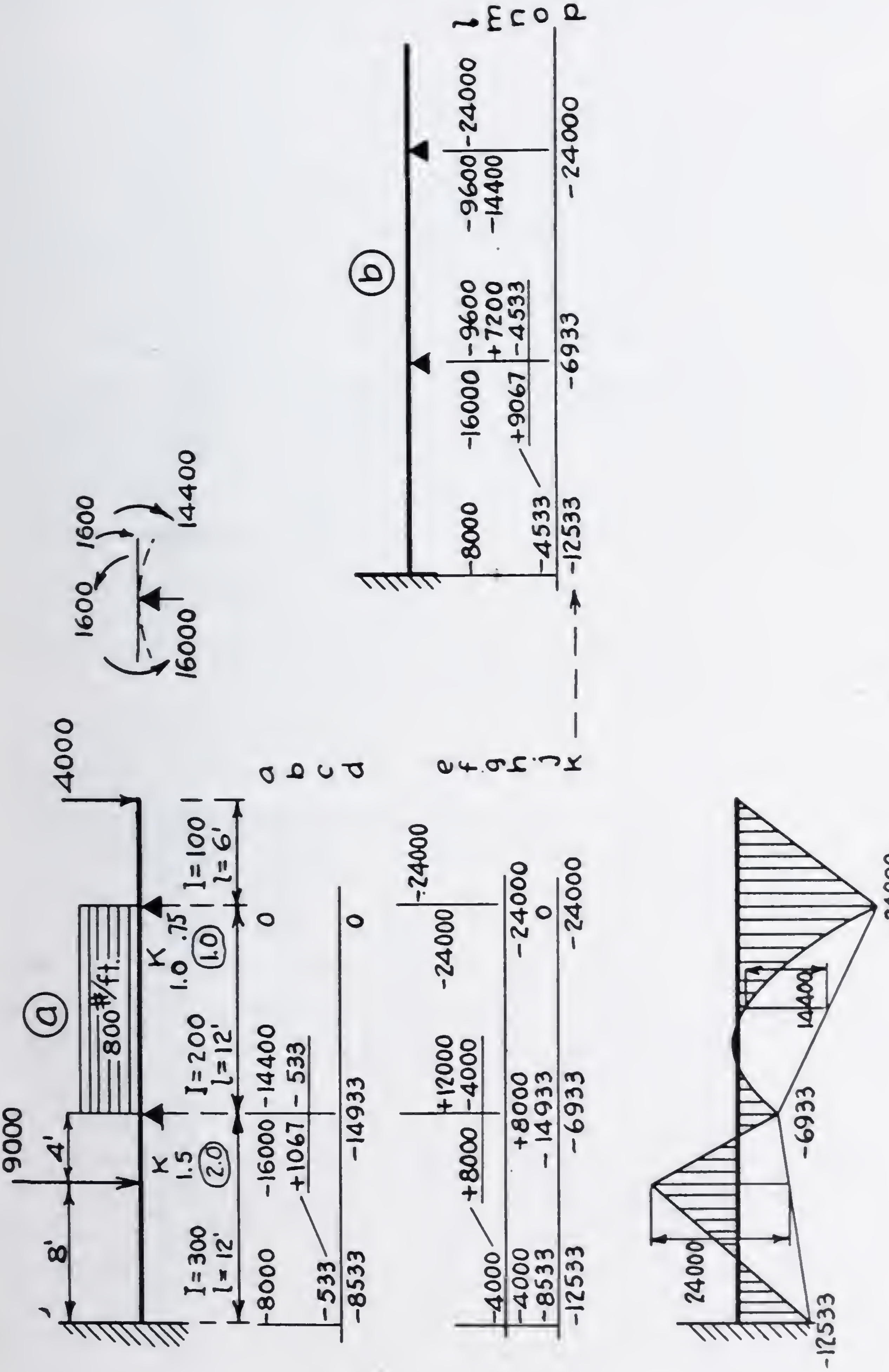
If one end of one span, say the left end, were free, the moments could be found either by starting the problem over again or by modifying the results already obtained. The first method is illustrated in lines e, f, and g. The middle support being locked, line e is identical with line a; but since the left end is free, the value of K for the left span is $\frac{3}{4}$ instead of 1 as in the problem above. Consequently, when the moment at the middle support is distributed, it is divided between the left and right spans in the proportion of $\frac{3}{4}$ to 1 as in line f, instead of equally as in line b. Half the moment of 9143 is carried over to the fixed right-hand support as in line g, but since the left end is free it can assume no "carry over" moment. The final moments at the supports, in line h, are obtained by addition.

The second method of attack is illustrated in Fig. 5(*e*). It is desired to find the effect of releasing the +4000 moment at the left end of line d; that is, neutralizing it by the application of a moment of —4000. Temporarily lock the middle support and apply the —4000 moment at the left end. A moment of +2000 is carried over to the middle support and will be distributed by unlocking the joint. From the standpoint of the middle support, the far end of the right-hand span is fixed and the far end of the left-hand span is free; hence, when distributing the moment, the value of K for the right-hand span will be 1, and for the left-hand span, $\frac{3}{4}$. The distribution and "carry over" being effected in lines l and m, the moments at all supports due to the application of the —4000 moment of line j, which are the same as would be generated by the release of the +4000 moment of line d, are obtained in line n by addition. These must be

added to the moments of line d, repeated for convenience in line p, giving the final moments of line r, from which the moment diagram may be constructed.

Of the two methods, the first leads at once to a direct answer, but the second method makes possible the free play of judgment and opinion. It would be just as easy to release, say, 2000 at the left end as to release the whole 4000; and, if the engineer doubts the complete fixation of either end, he may release whatever moment his judgment indicates and quickly trace the effect throughout the structure.

A continuous beam with a cantilever end may be handled as in Fig. 6(*a*) or 6(*b*). Let us first consider Fig. 6(*a*). The moment over the right support is dependent only upon the loads on the cantilever. Variations in the loads on either of the other spans will merely change the slope of the beam at the right-hand support without affecting this moment. Consequently the beam may be regarded as fixed at the left end and freely supported at the right-hand support. Neglecting temporarily the cantilever end, and locking the beam at the middle support, the end moments in the left-hand span are found as in Fig. 2(*e*) and the end moment in the right-hand span is found as in Fig. 4(*f*), these moments being recorded in line a. As shown in the thumb-nail sketch, the lock at the middle support is called upon to resist the difference in moment at the adjoining ends of the beams meeting over this support; that is, the lock is contributing a clockwise moment of 1600. Unlocking, or releasing this restraint is equivalent to applying the counter-clockwise moment of 1600 shown in the thumb-nail sketch, and this 1600 must be distributed in proportion to the K values of the two spans with reference to the middle support. The $\frac{I}{l}$ values of the left and right spans are to each other as 1.5 and 1, respectively; but since the "far" end of the right span is free, the relation of the K values is as 1.5 to 0.75, or, for simplicity, as 2 to 1. The distribution and "carry over" of lines b and c being effected, the moments at the supports, for all loads except that on the cantilever, are found by summation in line d. The effect of the cantilever load is determined in lines e, f, g, and h. This must be added to line d, repeated for convenience in line j, and the final



a
b
9000
4000
800#/ft.
I=300
l=12'
I=200
l=12'
I=100
l=6'
1600
1600
16000
14400
-24000
-6933
-12533
24000
14400

Fig. 6

moments at the supports are found in line k, by the addition of lines h and j. The resulting moment diagram is drawn below.

Fig. 6(*b*) shows how the results may be obtained in one operation. Without neglecting the cantilever load, both supports are locked, the end moments are computed and recorded in line l. When the right-hand support is unlocked, the moment at the left of this support is increased to —24,000, an increase of —14,400. Half of this increase is carried over to the middle support, with opposite sign, as in line m. At the left of the middle support the moment is —16,000, while on the right it is —9600 + 7200 = —2400; that is, since the middle support is still locked, the negative moment on its left is 13,600 more than on its right, the lock itself exerting the 13,600 clockwise moment required for equilibrium. Unfastening the lock is equivalent to applying a counter-clockwise moment of 13,600, which is distributed in line n to the left and right of the support in the ratio of 1 to $\frac{3}{4}$. In line o is given the moment carried over to the fixed end, and line p, found by summation, gives the final moments at the supports. Compare with line k, Fig. 6(*a*).

A three-span beam, fixed at the outer ends, and carrying an unsymmetrical load, is shown in Fig. 7(*a*). For simplicity, K has been taken as 1 in all spans. With all supports locked, the end moments in all spans are computed. Support 2 is then released, the moment distributed between spans 1 and 2, and the "carry over" moments of —4000 and +4000 brought over to supports 1 and 3. Since support 1 is never released, the —4000 it thus acquires simply "stays put." Support 2 is now locked again and support 3 released. The 4000 moment at this point is distributed between spans 2 and 3 and the "carry over" moments brought over to supports 2 and 4. That moment carried over to support 4 also remains unaltered, but the balanced condition at support 2 has been disturbed. Relocking support 3 and releasing support 2, and proceeding back and forth, successively balancing the moments at supports 2 and 3, a condition of virtual equilibrium is soon reached. The degree of precision is optional, just as it is in the computation of the value of π or any of the trigonometric functions. It is worthy of note, however, that had the moments been added up at line XX the sums would not have been greatly different from those finally obtained, and would thus

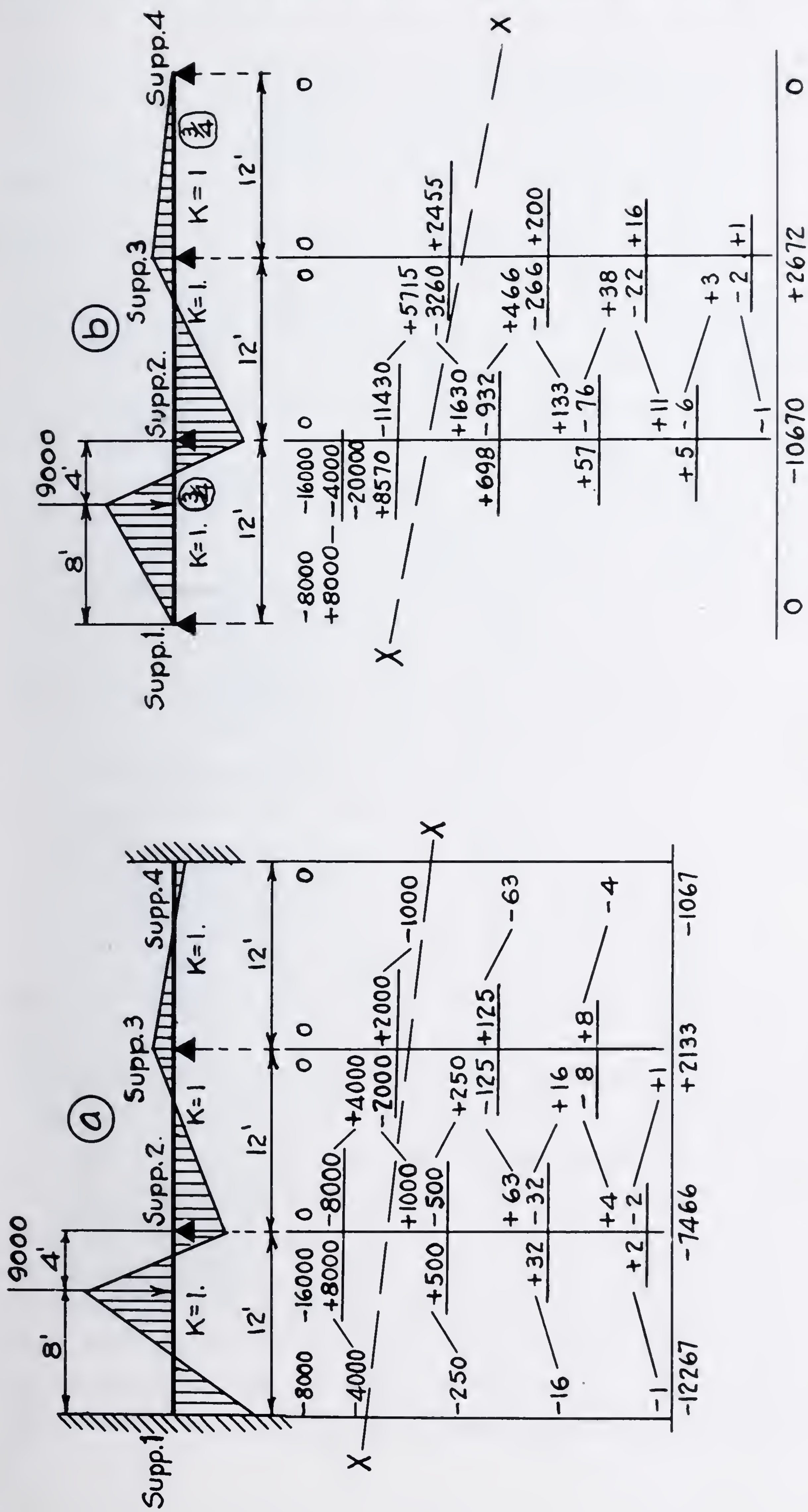
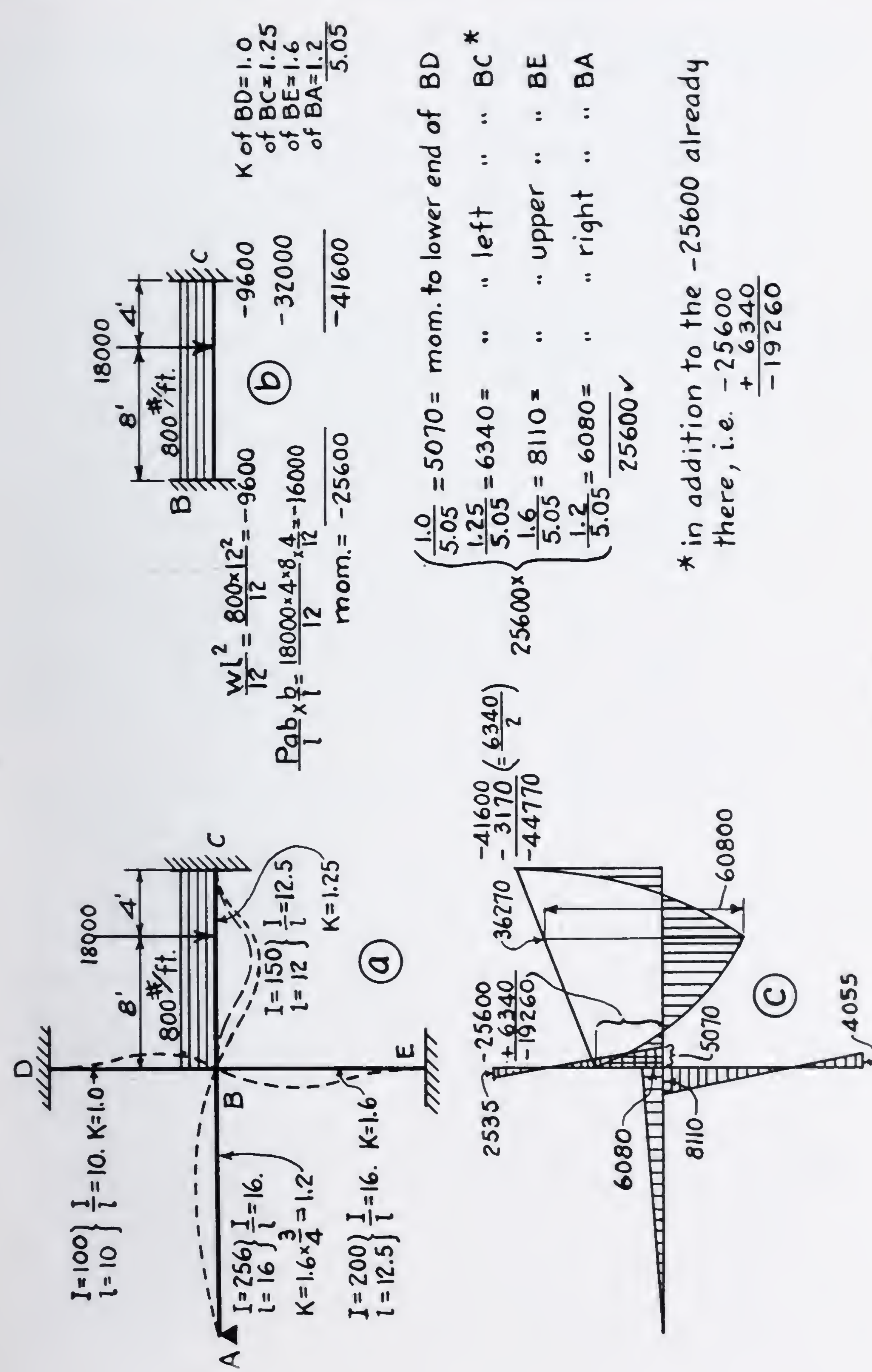


Fig. 7

quickly give a designer an idea of the nature of his problem, if not actually giving results sufficiently close for design purposes.

Had both ends of the above beam been free, the procedure would be the same as in Fig. 7(*b*). The value of K of each end span is reduced from 1 to $\frac{3}{4}$; and since both ends are free, the tabulation never gets away from the two interior supports. The process is similar to that in Fig. 7(*a*), and here also the degree of accuracy obtained at line XX should be noted.

In actual construction, supports may offer resistance to the free rotation of the supported beams; for example, beams may frame rigidly into columns which will themselves deflect when loads are applied to the beams. Such a case is illustrated in Fig. 8, which is merely a variant of Fig. 3(*j*), and can be treated in the same way. Locking joint B against rotation, the moments at ends B and C of span BC are computed in Fig. 8(*b*). The moment of —25,600 at the left end acts clockwise, the resisting moment of the lock being counter-clockwise. Members BA, BD, and BE, not being acted upon by any moments, remain straight, but member BC is bent as shown by the broken line. Releasing the joint is equivalent to applying a moment of opposite character to that of the lock and equal to it in magnitude; that is, applying a clockwise moment of 25,600 to the joint. Joint B being rigid in that all members meeting at this point must rotate through the same angle, this moment is divided among the four members meeting at B in proportion to their K values, the effect being to bend members BA, BD, and BE and partially to straighten out the member BC, as shown by the dotted lines. The effect on BC may be regarded as a relief from negative moment, or the application of positive moment, which may be better understood if in a beam we consider "belly down" curvature as indicative of positive moment and "belly up" curvature indicative of negative moment. The apportionment of the clockwise moment of 25,600 to the adjoining ends of the members meeting at B is given in the table, and the moment remaining in the left end of BC is seen to equal the sum of moments in the adjoining ends of the other three members. "Carry over" moments equal to one-half the magnitude of those at the B end of the members BC, BD, and BE, respectively,



K of BD=1.0
of BC=1.25
of BE=1.6
of BA=1.2
5.05
18000
8'
4'
800#/ft.
B
C
b
-9600
-32000
-41600
wL²/12 = 800×12²/12 = -9600
Pab/l × b/l = 18000×4×8/12 × 4/12 = -16000
mom. = -25600
1.0/5.05 = 5070 = mom. to lower end of BD
1.25/5.05 = 6340 = " " left " " BC *
25600× 1.6/5.05 = 8110 = " " upper " " BE
1.2/5.05 = 6080 = " " right " " BA
25600✓
* in addition to the -25600 already there, i.e. -25600 + 6340 = -19260
I=100, l=10, I/l=10. K=1.0
D
I=256, l=16, I/l=16.
K=1.6×3/4=1.2
I=200, l=12.5, I/l=16. K=1.6
A
E
I=150, l=12, I/l=12.5
K=1.25
a
-25600
+6340
-19260
2535
36270
-41600
-3170
-44770
(=6340/2)
60800
5070
6080
8110
4055
c

Fig. 8

will appear at points C, D, and E, and the complete moment diagram is shown in Fig. 8(*c*).

Thus far, except in Fig. 8(*c*), we have followed the usual convention in drawing moment diagrams; that is, positive moments have been plotted upward and negative moments downward from the base-line. In cases involving members with axes not in a straight line (such as a bent), it becomes simpler to draw these diagrams if they are plotted on the tension side of the member. For example, the tension side of a simple beam is below, and following the above suggestion the moment diagram would be drawn below the axis. Similarly for a continuous beam, in the region of negative moment, where the upper side is in tension, the moment diagram would be drawn above, and in the region of positive moment below the axis. It will be seen that these diagrams are merely the usual ones drawn upside down. There is no advantage in this method where beams alone are concerned; but, in difficult cases, if the shapes of the deformed structure can be approximated, the moment diagram can readily be sketched. In the remainder of this discussion, therefore, moment diagrams will be drawn on the tension sides of the respective members, as was done in Fig. 8 (*c*).

In the original paper, Cross proposed certain sign conventions, since none exist for columns, and one or two of those contributing to the discussion* have suggested still further simplification. We shall proceed, however, without introducing any further new ideas, and the reader may check up on the above suggestions at his convenience.

Consider now the symmetrical bent of Fig. 9(*a*), pinned at the lower end of each column and symmetrically loaded. Because of the symmetry of form and loading, corners B and E will not suffer any sidewise motion during the deflection of the members; and, these joints being rigid, the angles between the columns and the top girder will remain 90 degrees during and after rotation. In addition to the vertical reactions, V, there will be developed horizontal reactions, H; in fact, the curvature of the columns may be regarded as being caused by these horizontal reactions, since without them the columns would remain straight and assume the respective positions BG and EK. Treating each column as a free body it will be seen

*L. E. Grinter, *Proc. A. S. C. E.,* Sept. 1930, v. 56, p. 1748; A. H. Finlay, *Proc. A. S. C. E.,* Oct. 1930, v. 56, p. 1913; E. C. Hartmann, *Proc. A. S. C. E.,* May 1931, v. 57, p. 744.

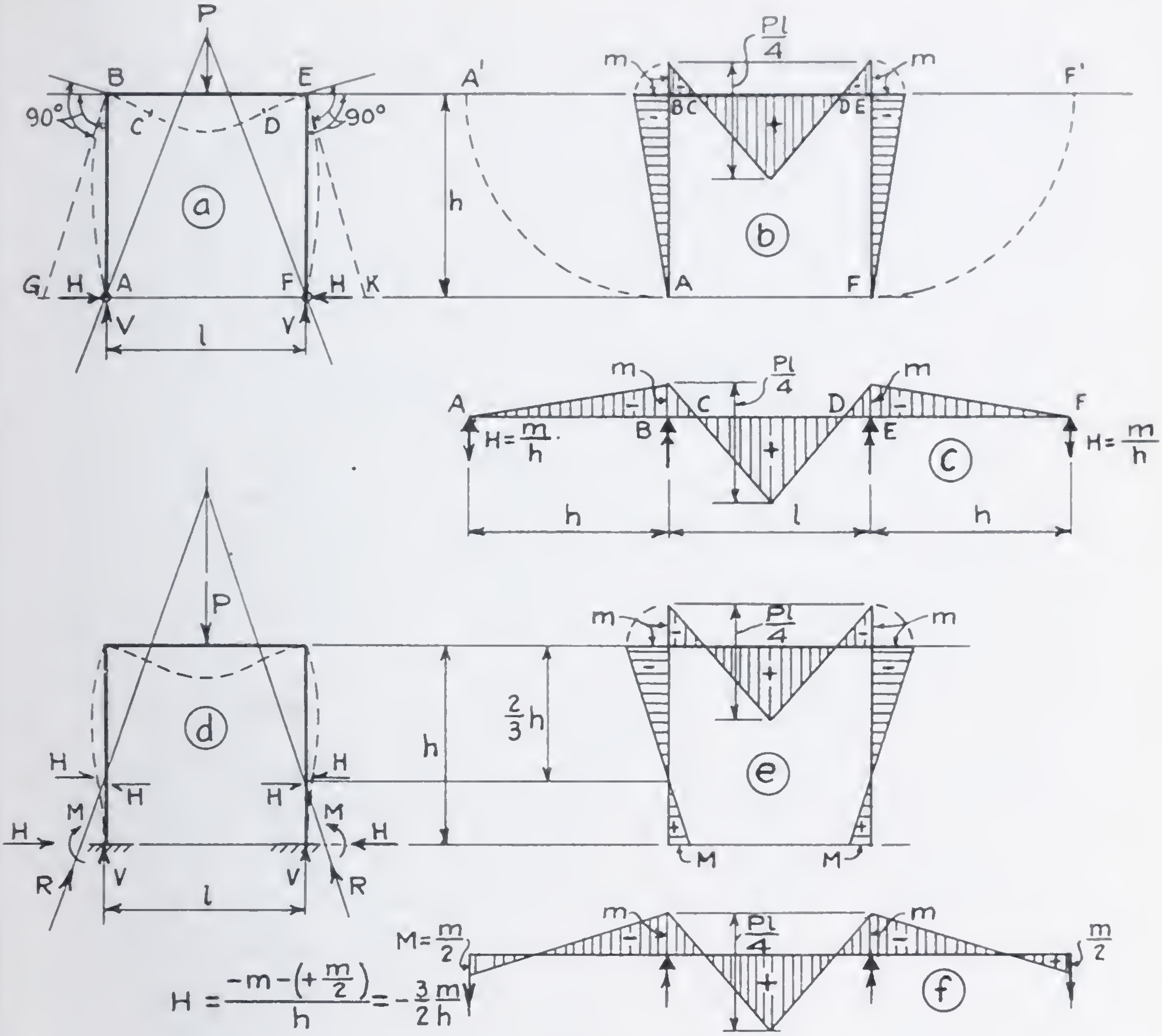


Fig. 9

that the moment increases from the bottom upward to a maximum m = Hh at the top. Isolating each joint B and E, it will also be seen that the moment at either end of the girder must equal the moment at the top of the adjoining column, and with this information the shape of the moment diagram may be sketched as in Fig. 9(*b*). The magnitude of H, and consequently the value of m, depends upon the elastic properties of the girder and columns, and is as yet unknown. If, however, columns BA and EF with accompanying moment diagrams be conceived of as being rotated to positions BA^1 and EF^1 the moment diagram will now appear as in Fig. 9(c). This is the same as the moment diagram of a three-span beam, and so long as there is no side sway, any bent may be analyzed as a continuous beam. Following the procedure of Fig. 7(*b*), the value of m may now be determined directly, and from it the magnitude of H if desired.

A symmetrical bent, symmetrically loaded, but having the lower ends of the columns fixed, is shown in Fig. 9(*d*). In this case a moment, M, is developed at the bottom of the column, and from previous considerations we know that its magnitude will be one-half as great as the moment applied by the girder to the top of the column. Fig. 9(*e*) shows the shape of the moment diagram, and values of m and M may be determined as in Fig. 9(*f*), following the procedure of Fig. 7(*a*). The value of H is found by dividing the algebraic difference of the end moments in the column by h. See Fig. 1(*c*).

The extension of the above treatment to multiple symmetrical bents symmetrically loaded, the bent shown in Fig. 10(*a*), for example, is obvious, the methods of dealing with single bents (Fig. 9) and multiple members (Fig. 8) being all that are necessary. There will, of course, be a break in the moment curve for the beam at the top of each interior column, representing the moment taken by the columns at these points.

Bents unsymmetrical in form or loading will lurch sidewise when the load is applied, and special means may be required for their analysis. The symmetrical pin-ended bent of Fig. 10(*b*) presents no difficulties, since due to its symmetry the horizontal reactions are each equal to one-half the load H, and the moment diagram, Fig. 10(*c*) may be drawn at once. In the case of the symmetrical fixed-end bent of Fig. 10(*e*) the problem is not so simple; for, although each horizontal reaction is known, the position of the points of contraflexure in the columns, and hence the magnitude of the moments at the top and bottom of the columns, is dependent upon the relative stiffness of column and girder. All that is known is that in each column the point of contraflexure is more than half way up the column, that the numerical sum (not algebraic) of the moment at the top and bottom of the column is $\frac{H}{2}h$, and that the shape of the moment diagram is as sketched in Fig. 10(*f*). Magnitudes will be discussed later.

Before taking up numerical examples the procedure in such a case is outlined as follows. Lock the tops of the columns in such a manner as to prevent rotation but yet to permit side sway under the action of H. The deformed structure will then appear as in Fig. 10(*h*). The locks will exert a restraining moment at the top of

each column and there will be an equal moment at the bottom. As yet there will be no moment in the girder, since it remains straight. Now imagine a pin to be pushed through joint B^1 and another through joint C^1 at the tops of the columns, and let the locks at these points be released. Immediately there will be a rotation about points B^1 and C^1, but additional side sway is prevented by the pins. With

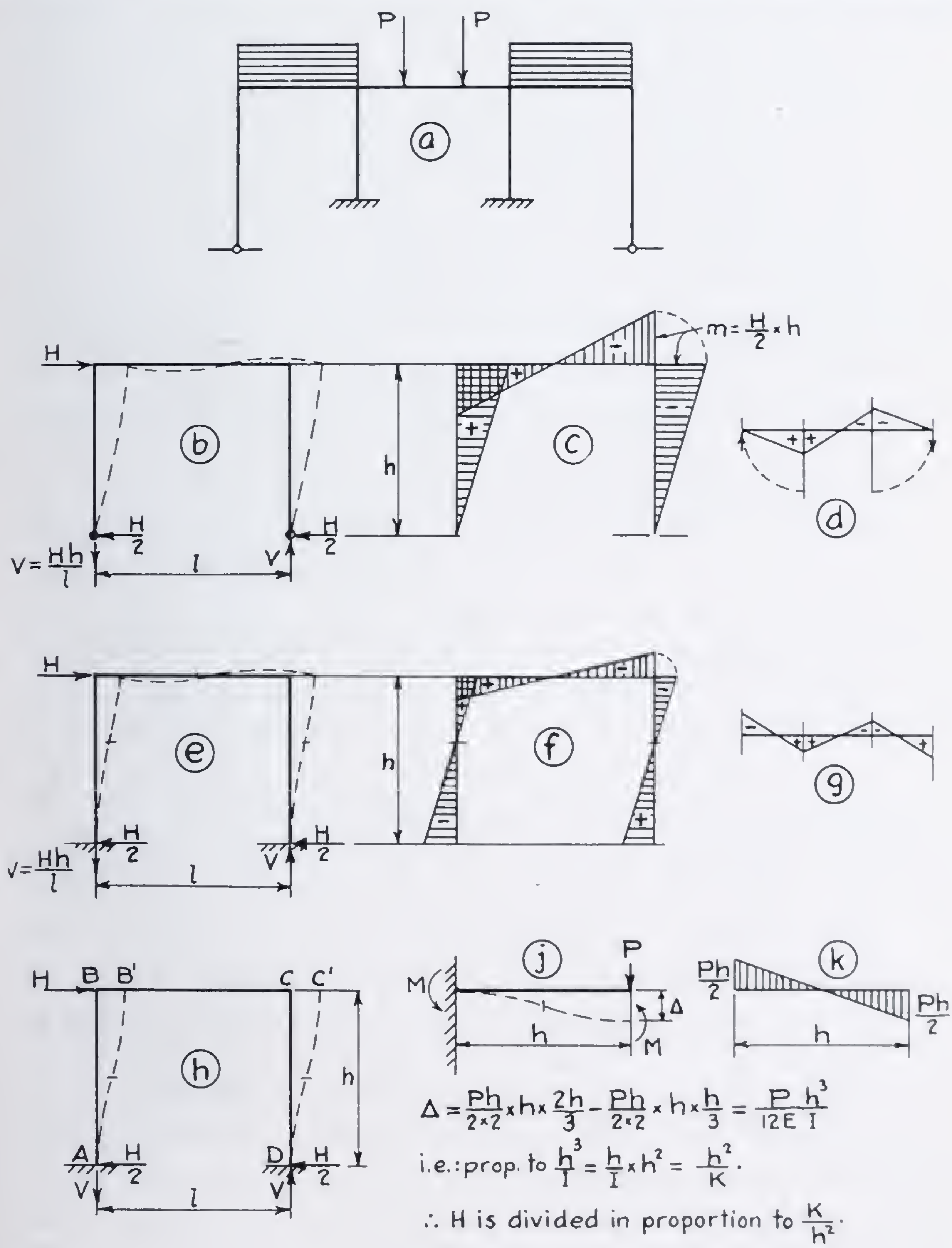


Fig. 10

the release of the locks and the rotation at points B^1 and C^1 the moments at the tops of the columns are distributed between the columns and the girder, moment in the girder being increased, and the moment in the columns being relieved. With the lessening of the column moments the magnitude of the horizontal reactions is proportionately diminished; but since ΣH must equal zero it is evident that the pins are receiving horizontal thrust that should be taken by the reactions. If now the points B^1 and C^1 are locked against further rotation, the pins removed, side sways again permitted in the direction of H until the reactions become $\frac{H}{2}$, pins reinserted, locks removed, rotation again permitted, new moments distributed, and new values of the horizontal reactions computed, a much closer approximation to the true conditions will be obtained. This process might be repeated again and again till a satisfactory degree of accuracy is obtained, but such repetition is unnecessary. It is evident that each repetition is just like the one preceding except that all new magnitudes are proportionately less than those previously found. It is evident, too, that exact results have been obtained when, after a sufficient number of repetitions, the sum of the accumulated values of both horizontal reactions equals H. The final values of all moments will therefore bear the same relation to the values of the corresponding moments after the first pinning and release of locks as the true values of the horizontal reactions bear to the computed values of these reactions after this first pinning and release of locks. Therefore it is necessary to distribute moments at B^1 and C^1 only once, compute the values of the corresponding horizontal reactions, and multiply all moments by the ratio of the real horizontal reactions to those just computed.

The real magnitudes of the horizontal reactions should be discussed briefly. In the symmetrical bent of Fig. 10(e) it is evident that the value of each horizontal reaction is $\frac{H}{2}$. In unsymmetrical bents the horizontal reactions are not equal, the stiffer column resisting the greater part of the thrust H, but their sum must equal the applied horizontal load. When the tops of the columns are constrained to move horizontally without rotation, and both lower ends are either pinned or fixed, as in Fig. 10(h), the thrust H is divided

between the columns in proportion to their respective $\frac{K}{h^2}$ values. This may be proved as follows. Let Fig. 10(j) represent one column, turned horizontally for convenient study, deflected under the load P and having a moment, M, sufficient to keep the free end horizontal. From its symmetry there will be a point of contraflexure at the middle, and M will equal $\frac{Ph}{2}$. Fig. 10(k) is the corresponding moment diagram, and the expression $\triangle = \frac{Ph^3}{12EI}$ is found from theorem 2. If we let K represent $\frac{I}{h}$ then $\triangle = \frac{P}{12E} \times \frac{h^2}{K}$. For another column, $\triangle_1 = \frac{P}{12E} \times \frac{h^2_1}{K_1}$ under the same load. To deflect the second column the same distance as the first (that is, to make $\triangle_1 = \triangle$), a different value of P would be required; or for the second column we may write $\triangle = \frac{P_1}{12E} \times \frac{h^2_1}{K_1}$. Setting the two expressions for $\triangle$ equal to each other we have $\frac{P}{12E} \times \frac{h^2}{K} = \frac{P_1}{12E} \times \frac{h^2_1}{K_1}$, or

$$\frac{P}{P_1} = \frac{\dfrac{h^2_1}{K_1}}{\dfrac{h^2}{K}} = \frac{\dfrac{K}{h^2}}{\dfrac{K_1}{h^2_1}}$$

, which was to be proved. If one leg were free, it would take only one-fourth as much thrust as if it were fixed, since in this case $\triangle = \frac{Ph^3}{3EI}$.

The application of the above principles will be illustrated by one comprehensive example. Consider the bent of Fig. 11(a), loaded as shown, and having members in which the values of K have been made equal for convenience. The loads will be treated separately and the effects added later, the vertical load being dealt with first. First, regarding the bent as a three-span beam fixed at its outer ends, the fixed-end moments at the ends of the middle span are computed and tabulated in line a of Table 1. This is equivalent to locking the tops of the columns against rotation and side sways, and then finding the end moments in the girder. These moments now are distributed and finally added up in line b to give the true moments at points A, B, C, and D when side sway is prevented. This step is equivalent

to pinning the tops of the columns and successively unlocking and locking the top of each column, without removing the pins, until equilibrium has been obtained. The moment diagram may be drawn for this stage of the solution if desired, as in Fig. 11 (*b*), but this is not necessary. The end reactions are now computed and found (line c) to be 1440 and 960 at the bottoms of the left and right columns, respectively. In the actual bent such a condition can not

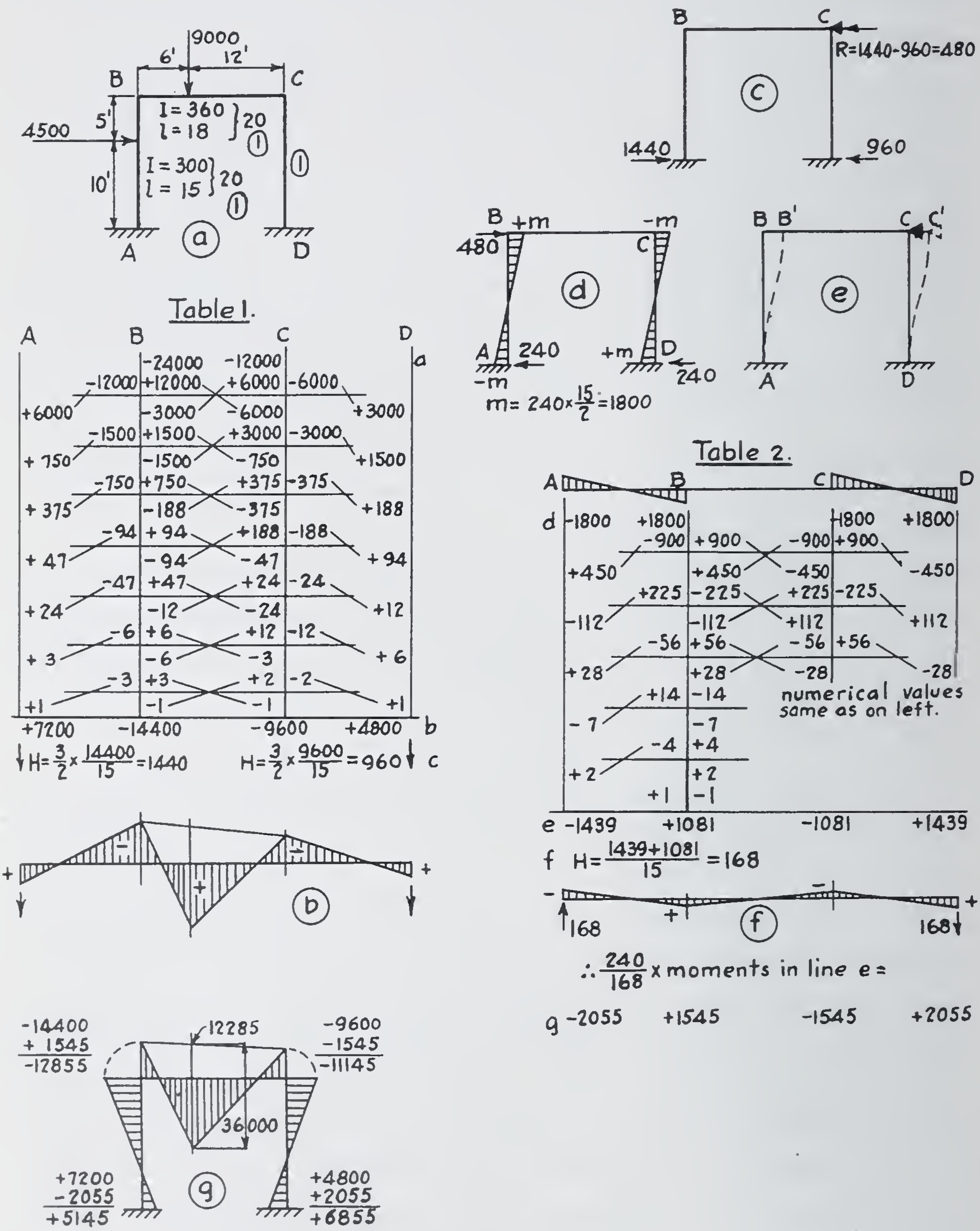


Fig. 11

obtain; for, since the load is vertical, the horizontal reactions must be equal in order that ΣH may be zero. Hence it is apparent that the imaginary pins in preventing side sway are exerting a virtual horizontal reaction, R, equal to the difference in the horizontal reactions, as in Fig. 11(*c*). If now the tops of the columns be locked against further rotation and the pins removed, the effect will be equivalent to removing the reaction, R, which is the same as applying a new force of 480, acting toward the right, at the top of the bent. See Fig. 11(*d*). This force will produce new horizontal reactions of 240 each at the points A and D. (If the K values of the columns had not been equal these reactions would have been proportional to the $\frac{K}{h^2}$ values of the columns and their sum would have been 480.) The resulting moment is 1800 at the top and bottom of each column. These moments have been drawn in Fig. 11(*d*) and tabulated in line d of Table 2, Fig. 11. The accompanying side sway is shown in Fig. 11(*e*), the deformation of Fig. 11(*c*) being neglected. If now the pins be again inserted at B^1 and C^1, and the locks successively released and relocked, the bent will spring into a new shape, rotating farther at B^1 and C^1 until the moment at the top of each column is once more equal to the moment at the adjoining end of the girder. This process is indicated in Table 2, and line e represents the corner moments after side sway under the 480 force, pinning, and release of locks. As before, a moment diagram for this stage may be drawn if desired, as in Fig. 11(*f*), although this is not essential.

A check of the horizontal reactions now reveals that their magnitude is only 168 instead of 240, but this is due to the fact that when the locks were released further side sway would have taken place if it had not been prevented by the pins. As mentioned before, the above process might be continued through several more approximations (the next horizontal top force being $240 - 168 = 72$), but it will be seen that in the end the corner moments due to side sway will be $\frac{240}{168}$ times those of line e. These have been computed and written in line g. The moments without side sway, line b, and those due to side sway, line g, are now added, and the diagram for the vertical load is shown in Fig. 11(*g*).

The horizontal load and its effects are discussed in Fig. 12. Assuming the column AB as locked at the top both against rotation and side sway, the moments at the ends are computed and recorded in line a of the first table in Fig. 12. Unlocking the top of the

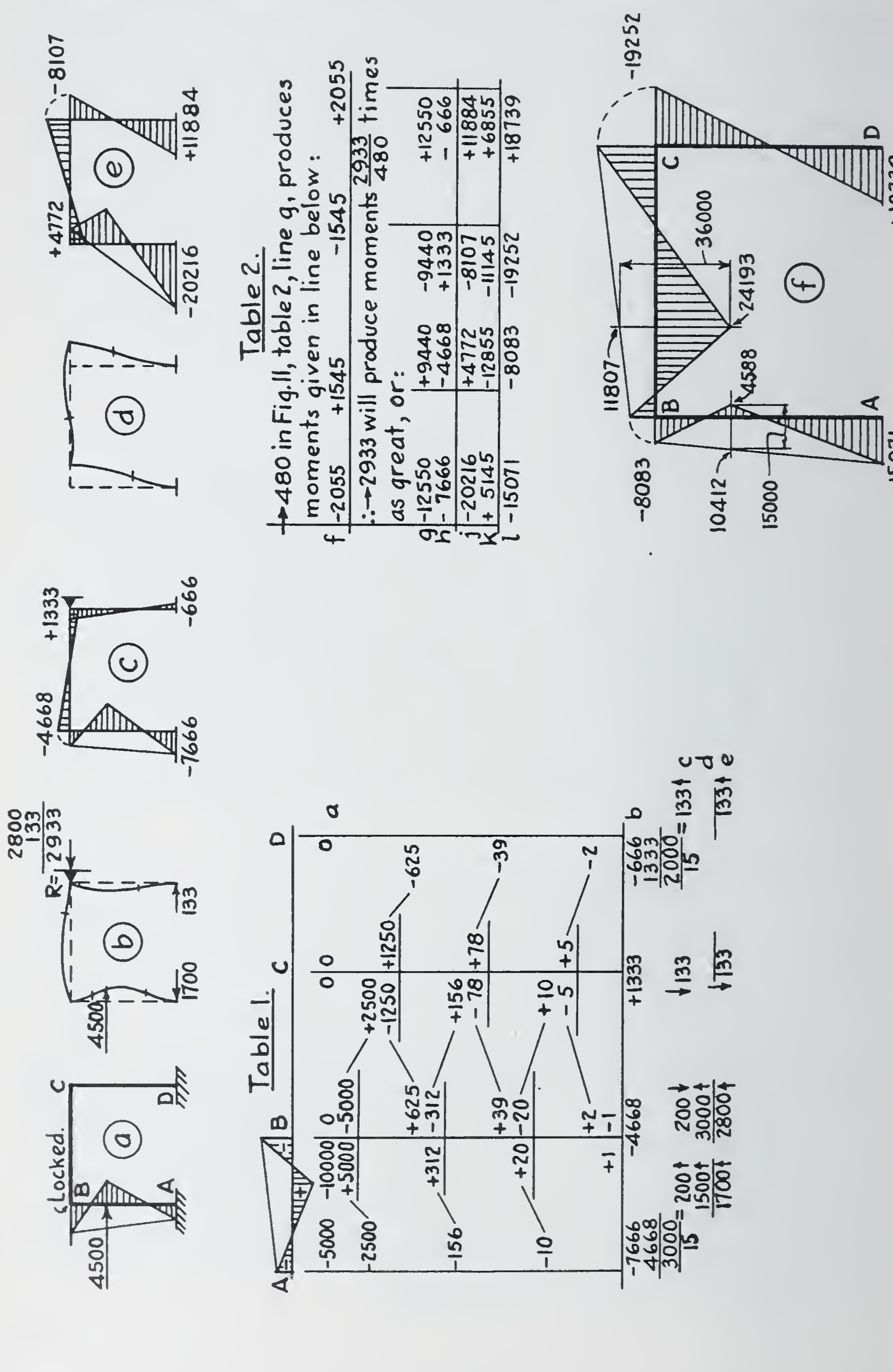


Fig. 12

column, but still preventing side sway, the moment at B is distributed around the frame until equilibrium is established, giving the moments in line b. The moments alone produce the horizontal reactions at the tops and bottoms of the columns computed in line c; and with side sway prevented, the 4500 load produces at A and B the horizontal reactions recorded in line d, just as in a simple beam. The horizontal reactions due to simple beam load plus those due to moments are found in line e by adding lines c and d. The deflected structure and the horizontal reactions at this stage are shown in Fig. 12(*b*), the top reaction being that required to prevent side sway, and the corresponding moment diagram is shown in Fig. 12(*c*).

Now the removal of the pins—that is, the withdrawal of the horizontal reaction at C—is equivalent to the addition of a horizontal force of 2933 acting toward the right at this point. The moments produced could be computed as was done in Fig. 11, but it will be more expeditious to find them by direct proportion, as follows. In line f of the second table of Fig. 12 are written the moments due to a force of 480, as found in Fig. 11, Table 2, line g. The moments generated by the force of 2933 will be $\frac{2933}{480}$ times as great. These are recorded in line g of Table 2 (Fig. 12). Adding to these the moments of line b, Table 1 (Fig. 12), repeated in line h for convenience, gives in line j the total moments at A, B, C, and D for the horizontal load of 4500. The deflected structure at this stage and the corresponding moment diagram are shown in Fig. 12(*d*) and 12(*e*), respectively. The great effect of side sway under horizontal loads upon the shape of the deflected structure and moment diagrams is evident upon comparing Fig. 12(*b*) with Fig. 12(*d*) or Fig. 12(*c*) with Fig. 12(*e*).

The corner moments due to the application of both vertical and horizontal loads are found by adding to line j the moments shown in Fig. 11(*g*), repeated for convenience in line k, Table 2 (Fig. 12), the results being given in line l. Having these corner moments, the complete diagram may now be constructed as in Fig. 12(*f*).

In the illustrations of Cross's method so far given, the method has been applied to common cases of continuity and rigid frame analysis. The author himself and several of those discussing the

paper give other applications,* but the great advantages of the method are not limited to its use as a sole method of analysis. It is a convenient tool to use in conjunction with other methods. For example, in the study of translations or rotations of continuous arches having elastic piers, it may be combined with any of the methods of arch analysis. The writer is firm in the conviction that this method will soon be one of the most used tools in the designer's kit, and trusts that this full discussion of its elementary applications will help to pave the way for its speedy adoption.

*R. A. Black, *Proc. A. S. C. E.*, Nov. 1930, v. 56, p. 2039; H. E. Wessman, *Proc. A. S. C. E.*, Nov. 1930, v. 56, p. 2044; R. R. Martel, *Proc. A. S. C. E.*, Feb. 1931, v. 57, p. 313; C. T. Morris, *Proc. A. S. C. E.*, Feb. 1931, v. 57, p. 318.

DESIGN OF RIVER TOWBOATS*

By T. R. Tarn†

In the trying time in which we are now living, we are more concerned with the present order of things and with those shortly to come to pass than with those things which have become history. It is therefore deemed expedient, in reviewing the design of river towboats, to pass over the traditions handed down to us in song and story, and examine what now exists and what may be expected to develop.

By way of introducing our subject, we are, however, constrained to pause long enough to pay a well deserved tribute to the first fresh-water naval constructor and navigator of established reputation. From the record, we find that this man built a wooden cattle ship of considerable size, requiring for its completion something like one hundred years. That he was resourceful and purposeful in the face of much ridicule and seeming impossibilities is disclosed by the confidence he exhibited in loading his vessel with its living cargo prior to the time that it was launched. That he had full confidence in his ability as a navigator is evidenced by the successful completion of a cruise that weathered the greatest holocaust ever visited upon the earth. All of this is the more remarkable because it was accomplished without the assistance of chart or compass, rudder or sails, classification society rules, steamboat inspection regulations, public health service requirements, a seamen's act, or a moratorium of convenience.

Since that time, however, the waters of the earth have proved far more kind for the purposes of man. In particular, there is within the confines of this nation a gigantic network of navigable inland waterways that may be typified as a "national tree," with roots represented by the mouths forming the delta and firmly embedded in the Gulf of Mexico; with a trunk extending to Cairo, and thence with long, far-reaching branches spreading out over an area of over one million square miles to "shade" a population of over fifty millions of people.

Some of the branches of the tree produce "fruit" in greater quantity than the others. This for the reason that the "tree sur-

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geons" have directed their attention to pruning and healing certain branches. In consequence of which "birds" have been attracted and built "nests" among the branches in order that their "young" may be raised and go forth and "sing." To those not so fortunately favored by the treatment and care known to have been discriminately bestowed, and in spite of the fact that the leaves may fall earlier or the fruit-bearing season may be shorter, it is now realized that the tree is sound in all of the branches which have suffered neglect and may in like measure produce an abundance of fruit and provide desirable nesting places.

In this we have a picture of the structure and possibilities of the extensive Mississippi River system, the existing and proposed navigational facilities and the characteristics of which are of vital importance in determining the type, size, power, draft, and service requirements to be incorporated in the design, construction, and operation of any craft to navigate successfully thereon.

For our present purpose we may consider the "trunk" and certain of the "branches" as affording an all-year-around navigable depth of nine feet and those "branches" not so favored as affording minimum navigable depths of four feet. For, like the proverbial chain and the link that determined its strength, the shallowest depth in any stream determines the depth at which a craft may continue to be water borne and thereby remain under operating control. In addition, the navigable depth of the stream definitely fixes the maximum power that may be advantageously placed aboard the craft. In turn, the amount of power desired and the available navigable depth point directly to the manner in which it may be most advantageously applied to the propulsion of the craft. As a result of fixed power and draft considerations, the hull structure may be decided upon; taking into consideration channel width, clearance between bridge piers, clearance height under bridges, radii of river bends, ice, drift and current, lock sizes, terminal facilities, class of service, speed and length of haul, not only for the propelling craft, but for the assembled fleet of barges as well.

Having examined the navigational considerations and the service conditions, we find that the power required to meet these conditions is influenced in large measure by the speed to be maintained on the available navigable depth, the form of the barges, and the formation

of the fleet of barges, all of which are very important with respect to the resistance to propulsion.

We may now look into the question of navigable depth and its influence on the resistance to propulsion.

As the slackwater system presumes a minimum navigable depth of nine feet, this depth, by reason of the slope of the river, must naturally obtain just under an impounding dam. This proving to be the case, then the navigable depth immediately above an impounding dam would be represented by nine feet plus the fall or slope of the river intervening between two succeeding impounding dams, which for our purpose we may safely assume as twelve feet.

Then, if the navigable depth is a factor in the resistance to propulsion, and this resistance becomes less as the navigable depth increases, we may expect to require less power to maintain the speed of the tow as we leave a dam and approach the next dam, as when headed down-stream; and, by the same token, we may expect a further reduction in the power required to propel the tow, at constant speed, as the depth of water increases to the minimum for which there is no further effect on resistance. To determine this depth, Admiral Taylor developed the formula $D = \frac{10\,HV}{\sqrt{L}}$, in which D is the depth of water in feet, V the velocity in knots, L the length of the formation in feet, and H the mean draft in feet. It shows the necessity for arranging tows with as great lengths as possible in order to reduce resistance.

What, then, is the measure for use in determining the amount of power to be placed aboard a towboat to propel a tow on a restricted depth of water; or, in other words, what are the resistances to propulsion and how do they vary as the depths of water vary?

The resistances to the progress of a craft through the water may be classified as frictional, and residual or wave-making. The first depends upon the area and character of the surface contacting the water. The second depends upon the shape or form of the craft, the speed, and the depth of the water. The resistance of the air, which in practice may be considered, can be neglected. Also, as we are considering river boats, the high resistance to craft operating in restricted channels—such as canals, which call for the consideration of the

ratio of the cross-section of the canal to that of the immersed portion of the craft, as well as the navigable depth—need not here be considered.

Obviously, such determinations are best made experimentally for each specific case. In the past, for the expected performance of shallow-draft, full-formed, slowly moving river craft recourse was had to published formulæ evolved as the result of tests predicated on finer-formed and more deeply immersed craft by reason of more definite and suitable data being unavailable. As a result of the lack of information to cover the subject as directly applicable to the design of craft for the navigation of inland waterways, the United States War Department, acting through the office of the Chief of Engineers, appointed a special board of engineers to make investigations which, among other things, included the following:

1. Consideration of devices for river transportation.
2. Experiments upon model towboats and barges.
3. Experiments upon paddle-wheels.
4. Investigations of methods in use on European rivers.
5. Consideration of cargo-handling appliances.
6. Discussion and determination of designs of experimental towboats and barges.

The work of this board and the continuing activities of subsequent boards have been productive of an ever increasing fund of valuable knowledge which directly applies, both theoretically and practically, to the problems of river navigation interests. With the conclusions of this board at hand we are now able to prepare economic studies of transportation problems, with greater assurance of the ultimate performance, in that economical formations of tows at various speeds and at various navigable depths for an acceptable number of barge forms are made available, together with performance characteristics of the most suitable types of towboats.

As an example of the decreased resistance of a single barge to propulsion as the navigable depth of water increases, we present a comprehensive table taken from the original report of the board, based upon Froude's formula and the result of tank experiments.

	Water		
	9 feet	12 feet	Deep
Total resistance (by experiment), pounds	4350	3250	2371
Frictional resistance (by formula), pounds	997	997	997
Residual resistance (difference), pounds	3353	2253	1374
Portion of resistance due to surface, per cent	22.9	30.7	42
Portion of resistance due to form, per cent	77.1	69.3	58

These results consider a barge 150 feet long and 34 feet in beam loaded to a draft of seven feet and propelled at a speed of 5¼ miles an hour in still water, and denote the rapidity at which the residual or wave-making resistance disappears as the depth increases. The frictional resistance, of course, remains constant at all depths by reason of the speed remaining constant.

It may here be added that the limiting factors in determining the dimensions of river barges are, for the most part, the strength consideration, the size of the locks, and the convenience in loading and unloading. It is quite obvious that where barges are assembled in fleet formation, the fleet acts in much the same manner as a unit barge having dimensions equal to those of the combined barges. This reduces not only the residual resistance by reason of the reduction of the speed-length ratio, but the frictional resistance as well, and this by reason of the elimination of the surface represented by the adjacent barge sides as surfaces in contact with the water.

This latter consideration, when taken in conjunction with the method of "flanking" practised on the Mississippi system, is full justification for the practice of towing "on the head" and prompts the statement that nowhere else on earth (the Yukon and one operation on the Nile excepted) are tows moved as economically and with as little expenditure of power as it is possible to move by this proved method. In shallow water, it has been found that three barges usually have less total resistance than two, and five frequently have less than four, which fact is evidenced by a tank test which disclosed a saving of approximately 25 per cent. for the fleet-formation method over the combined resistance of a similar number of single barges of the same dimensions when propelled at identical speeds.

To present a picture of what has been done in this direction we include a list of tows which passed down the river when the

hazards of navigation bore little resemblance to the most excellent conditions obtaining to-day.

Steamer *Sprague*. March 1898; Louisville to the South; 55,214 cargo tons; 1500 horse-power. (Bonson boilers.) This tow was 1000 feet long and 312 feet wide, and was made up of 60 pieces.
Steamer *Coal City*. January 1901; Cincinnati to Louisville; 24,750 cargo tons; 1000 horse-power. This tow was 1005 feet long and 182 feet wide, and was made up of 41 pieces.
Steamer *Sprague*. May 1904; Louisville to the South; 53,200 cargo tons.
Steamer *Henry Loughry*. June 1910; Bellaire to Louisville; 23,325 cargo tons; 1200 horse-power. This tow was 922½ feet long and 182 feet wide, and was made up of 38 pieces.

The ability of a towboat to propel, handle effectively, and safely deliver such large tonnages in a narrow, changing river channel, with fluctuating currents, and with bars, crossings, bridge piers and other physical structures in its path, by day and by night, over a course upwards of one thousand miles, not only points out the economy of the method, but the ability of the riverman as an outstanding navigator as well. While it is to be admitted that the above tows progressed with and not against the stream current, and while doing so the speed of advance, considering the stream current, varied from five to nine miles an hour; nevertheless, the accomplishment of securing into one compact fleet, in two cases, 60 flexible wooden barges covering an area of almost six acres and membering them to the propelling craft is worthy of more than passing notice.

Since we have shown the method and consideration by means of which the resistance of the tow may be determined, we are now prepared to fix the power, or thrust, of the towboat to overcome the resistance of the tow, bearing in mind that the resistance of the towboat to propulsion is also to be considered. This may readily be found by introducing but one assumption (the coefficient of propulsion, or the ratio between the effective horse-power and the indicated or shaft horse-power, to conform to the performance of the particular type of towboat it is proposed to utilize) in the following equation:

$$\text{Horse-power} = \frac{\text{thrust} \times \text{velocity}}{\text{coefficient} \times 33{,}000}.$$

As an addition, we have for consideration the reserve power considered necessary to overcome the high-velocity currents encountered during periods of high water and at other times, for affording a "sense of security" as when negotiating bends, bridges, or tortuous channels.

Having now arrived at the point at which we are ready to propel the tow we may proceed to examine and analyze the several methods of propulsion, the whole theory of which may be summed up in Rankine's words, "That propeller is the best, other things being equal, which drives astern the largest body of water at the lowest velocity." This conclusion applies not only to liquids but to gases (that is, to fluids in general), and with equal force to the propulsion of aëroplanes, rocket cars, etc., for the underlying principle is none other than the reaction due to imparting motion to a mass.

In order to accomplish our purpose we have:

1. The jet-propeller.
2. The paddle-wheel propeller.
3. The screw propeller.

While the first is not considered of much importance as an efficient propeller we may examine the possibilities later.

The second is very readily applied to river towboats and very desirable for shallow water. The wheels are usually placed at the side or the stern.

The third, in river practice, has always been placed at the stern, more frequently in tunnels or recesses, to permit of the application of greater power than could be applied if the wheels were fully immersed.

To examine the manner in which the paddle-wheel type of propeller is connected with the hull structure, and to obtain an idea of the various modifications to which it has been subjected, we include the following list with comments, reserving a statement of the performance until later.

1. Immediately abaft the stern supported on cantilever beams. The supporting value of these beams is usually supplemented by means of chains or by superimposed trusses. Rarely are they other than radial wheels. Frequently they may be of the so-called staggered type in which the buckets of one-half of the wheel are advanced

one-half of the intervening space between the buckets. The object is to reduce the intensity of the impacts in order to dampen the attending vibration. The result is to double the number of impacts, eliminate the only means of stiffening and of steadying the shaft at a critical point, and thereby cause its early failure, not as the result of overstress, but by reason of fatigue. Such a method is to be considered only in connection with the carrying of passengers.

2. Abreast the hull aft of the midlength, the method being designated as side wheels. Wheels so placed are for the most part independently driven and may be of either the radial or the feathering type. The former are usually built on a shaft supported as a simple beam and the latter, for certain classes of vessels, are built on projecting shafts on the cantilever principle.

This type of wheel may be placed in a recess formed in the stern of the hull. This method places the weight of the wheel assembly directly on the hull structure and permits of the more direct application of the wheel thrust to the structure, both of which are desirable. This location for the wheel is usually employed on vessels operating on tidal rivers where it is necessary to navigate stretches of open water. The protected location of the wheel reduces the tendency to "race." The disadvantages are that in shallow water the extensions of the hull act to prevent water from entering the wheel, and that the rudder reactions are greatly reduced.

A wheel of this type may also be installed between two separate hulls, as in the catamaran. In this instance we have the best example of a double-ended vessel, as the wheel may be placed amidship. This arrangement, the supporting of the wheel assembly on the hull structures, and the compact arrangement of drive made possible, are among the advantages. The disadvantages are that the high velocity of the wheel stream increases the frictional resistance of the hull, and that the rudders are not properly effective.

Again, we have the use of two independently driven wheels at the stern, abreast of the prolongation of the center portion of the hull. In this case the wheels may be operated to the same advantage as independently operated twin screws to secure the "turning effect" to be accomplished by rotating the wheels in opposite directions. Modifications of this method have been used by substituting a cantilever

beam extension for that of the hull prolongation. Aside from the turning effect due to the spread of the wheels, little advantage is gained other than the ability to use a wheel in the event of an accident to one of the wheels, and thereby utilize one-half of the power, for it is obvious that the rudder reactions (set up by the wheel streams, when the wheels are operated in opposite directions) are greatly reduced when the rudders are controlled as a unit.

We also have for consideration the use of a modification of the paddle-wheel in the form of a continuous paddle, or so-called "tractor" principle, in which paddles in a series are connected to endless chains or belts revolving about two drums usually placed at the midlength of the hull on each side and driven either independently or as a unit. When independently driven the ability to maneuver in the same manner as a side-wheel arrangement may be cited as the only advantage worthy of consideration. The claims that "slip" is non-existent and that the mass of water set in motion is due to the combined area of the immersed paddles has long been known to be a fallacy.

There have been many and varied modifications of the paddle-wheel with the object of increasing its effectiveness for transmitting the power to the water in the stream. An instance of what appeared to be a clever arrangement consisted of a water-tight cylindrical steel drum on the outer surface of which were fixed the usual number of radial paddles; or, as we say, buckets. The idea of the water-tight drum was to permit the deep immersion of the drum to obtain sufficient displacement to eliminate, in part, the usual load carried by the supporting members. An attempt to operate the boat resulted in it having to be towed to shore. Because the air entrapped by the entering buckets had no means of escape other than at the ends of the drum, the volume of water displaced by the wheel was insufficient to establish thrust to propel the boat.

Other modifications of the radial wheel have had for their object the elimination of the "tail-water lift." Usually, recourse was had to giving the buckets radial curvature or to altering the usual plane-axial surface to form sinuous and re-entering inclined surfaces. This was invariably found to impair the ability to operate either in a forward or in an astern direction with equal effectiveness—a valuable and outstanding feature of the radial wheel, which has caused the

river operator to adhere steadfastly to the radial type of wheel in the face of much adverse criticism, and a feature that is not found in any other rotating propeller.

Passing from the paddle-wheel propeller to the screw propeller we find fewer applications with respect to its location and association with the hull structure. Aside from the locations ordinarily found, they are usually installed under the stern of the hull in tunnels, or chambers, to permit of the use of a wheel of larger diameter than that justified by the available depth of water. When so installed, the upper portion of the wheel projects above the flotation line of the hull until the propeller, through its own action as a pump, fills the air-sealed tunnel or chamber, thereby effecting its total submergence.

Ordinarily, the unwatered portion of the wheel is not in excess of one-third of its diameter, and there is a loss, not only of the work required of the propeller to elevate the volume of water for continually maintaining the water in the tunnel, but of the work represented by the reaction of the stream issuing from the propeller against the tunnel. Also, the volume of water in the tunnel represents an equivalent deck weight. For the most part, such installations are twin-screw installations with the propellers turning inboard at the top when propelling "ahead." The purpose is to increase the ability to maneuver the boat, as will be explained later.

Generally speaking, the installation of twin screws in tunnels does not present any difficult constructional problems. The effectiveness with which under-water attachments may be made to the hull, the fact that they are borne directly by the hull structure, and that the wheel thrusts are delivered to the hull structure in a direct manner, are all very desirable.

There is, however, one very decided disadvantage in the use of screw propellers for use on river towboats. This is their inability to develop the same propulsive effort when operating in an "astern" direction as when operating in an "ahead" direction; and, it may be added, very little information has been published on the backing power of the screw propeller, either isolated or in conjunction with a ship's hull.

The ability of a river towboat to check the progress of its tow against the action of the stream current, especially when headed down-

stream, is very important. Ocean vessels may set a throttle or steaming condition when clearing port and not change the uniform operating condition for two or three thousand miles; or, in the event of mechanical failure, may float around for weeks at a time without loss of either ship or cargo; but the operation of a river towboat requires very frequent changes in the steaming condition with reversals of the machinery to maneuver the tow, while the limited amount of "sea room," in the event of floating when out of control, would prove to be disastrous to both boat and tow in a matter of minutes.

It is therefore to be noted that two features are necessary for incorporation in a river towboat—the ability to propel either ahead or astern, and the ability to maneuver the boat and the tow. *If the boat excels in one of these features and lacks in the other, it is not a successful boat.* Much care is therefore necessary in applying the screw-propeller principle to river towboats to obtain the desired result. This care consists in the proper co-ordination of the hull structure with the associated propellers and rudders to produce the maximum propelling and maneuvering ability.

The use of a greater number of screw propellers than is represented by the twin-screw installation is of very doubtful value. The object of such an installation would be to secure a greater amount of power than the available navigable depth would justify being placed on a smaller number of propellers.

In the event of the installation of three or four screw propellers under the stern of a necessarily full-formed and beamy hull (and such installations have been advocated), the combined action of the propellers would result not only in increasing the dynamic pressure to be overcome, but also in increasing the settling or "squat" of the hull at the stern. Furthermore, the inboard screws when shoal places were encountered would not be as effective as the outboard screws, due to their inability to secure an unrestricted flow of water by reason of the proximity of the hull of the boat to the bottom of the river and the resulting restricted area for water flow, which condition of flow is aggravated by the frictional resistance not only of the hull itself, but also by the bed of the river. The hydraulic principle governing this condition is apparent when we consider the restricted channel of flow, the counteracting influence to flow by the movement of the

hull opposed to the water, and the lack of smoothness of the river bottom, all of which have more or less effect on the reactions to be obtained from a complicated rudder arrangement. Nor is it to be expected that a greater amount of power may be applied under like conditions by using bow screws. In a paper by Charles F. Gross and Charles Green, entitled "Some Considerations in Design of Ferry-boats," in the *Transactions of the Society of Naval Architects and Marine Engineers* (1926, volume 34, pages 219-248), we find the statement (page 225) that "We all knew that the bow propeller on a through shaft installation was practically worthless." Even if the reverse of this were true, the shoal water, ice, and floating drift hazard on the rivers would offset considerable advantage.

By way of assisting in selecting the diameters of propellers for tunnel-type towboats, we submit Fig. 1, which is based upon the nominal power and derived from the following equation:

$$\text{Diameter of propeller in feet} = \sqrt{\frac{S\,H\,P}{10}}.$$

To point out the efficiency to be expected from paddle-wheels and screw propellers, we quote directly from the second supplementary report of the Board of Experimental Towboats, dated June 17, 1929—"radial stern wheels from 10 to 26% for various boats, and for feathering wheels from 17 to 29.5%. The efficiency for the screw propeller boat was 40%." In the last sentence it is to be noted that the efficiency has reference to the ability to propel ahead and not astern.

Quite recently, not only towboats but barges were constructed of wood and assurance can be given that their construction was ingeniously conceived for the service of shipping coal and other products from this district. Due to the partial completion of the slack-water system in the Ohio River, and the navigational difficulties suffered by reason thereof, the wooden-hulled, hog-chained type of stern-wheel towboat was particularly developed to meet the seasonal flood conditions permitting of the shipment of the large and deeply laden combination fleets, and to return the empty fleets at times when the flood or high-water conditions had subsided.

These wooden vessels may be divided into three classes—the so-called "pool" type; the "upper" river type, which may be con-

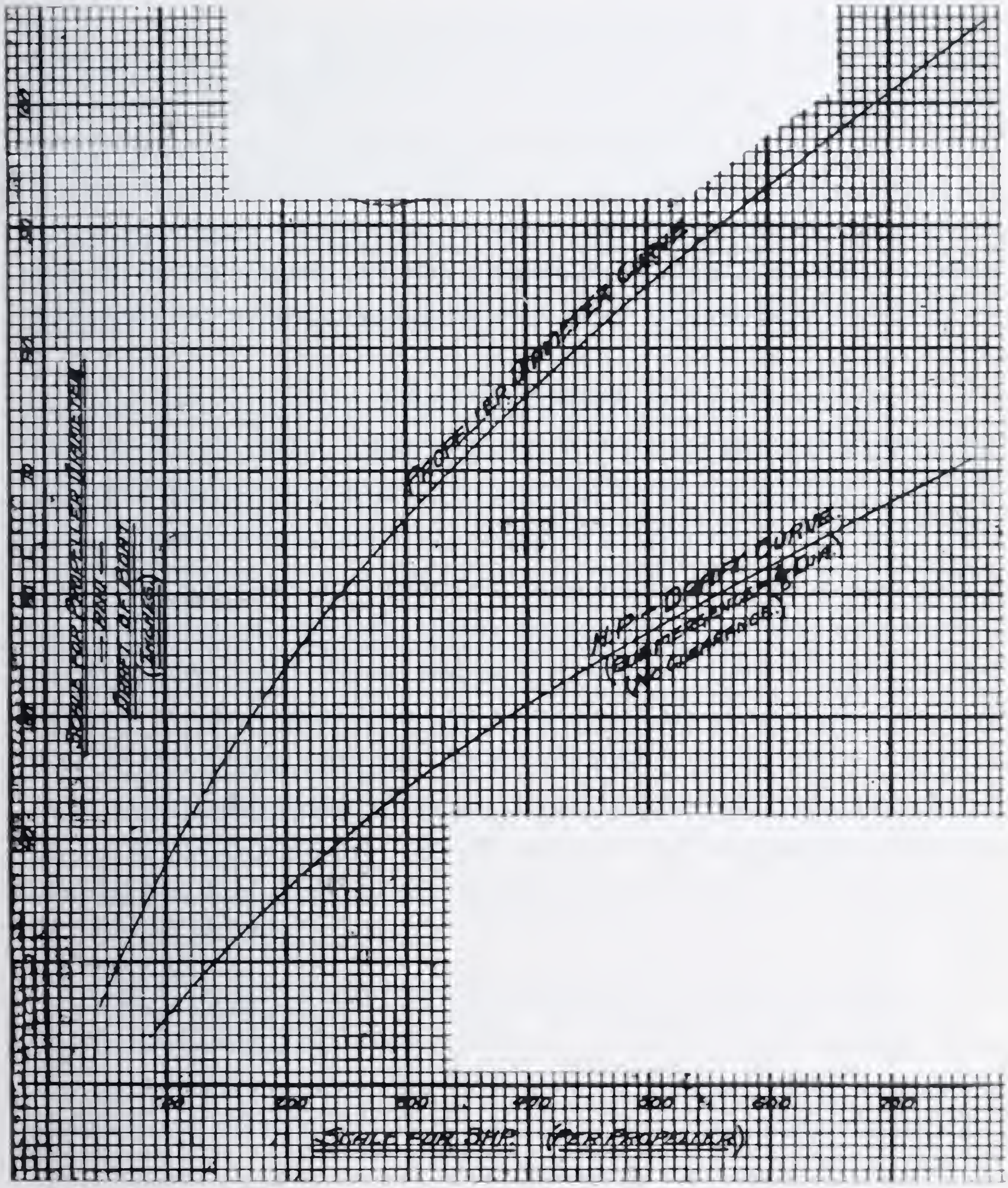


Fig. 1. Minimum Draft and Diameter of Propeller for Tunnel Boat.

sidered as operating between Pittsburgh and the falls at Louisville; and the "lower" or Mississippi River type, operating from Louisville to New Orleans. Variations of power and size in each type were as a rule patterned after the existing successful type as the result of the practical knowledge gained from a study of their operation, and not from factors governing the performance or the design as determined mathematically.

With the advent of steel construction, no real departure was made for a time from the tried and proved methods of construction. In fact, many structural features were faithfully duplicated with steel and little regard paid to the possibilities for the simplification of details of construction made possible through the use of steel. As an example of the methods employed during the transition period from wooden to steel construction we cite the general use of ⅛ inch of steel for each inch of thickness of lumber used in wooden construction.

Later, by reason of the passing of the individual coal operator who also controlled the river equipment which marketed his product, the entry of business interests with substantial engineering organizations into river transportation caused a gradual improvement to take place; but it was not until very recently that anything of a very definite and substantial nature was made available to form the basis for arriving at the scantlings of vessels to ply the rivers, but the American Bureau of Shipping has prepared a comprehensive tentative treatise on the subject. This, with the requirements of the United States Steamboat Inspection Service, and the information made available by the Experimental Towboat Boards previously referred to, has simplified the problems of the designer, the builder, and the operator alike.

For the purpose of recording a list of rules which were followed in the days of wooden boats, we cite the following, which were compiled over thirty years ago. They are based upon a steam pressure of 150 pounds gage, and D is the diameter of the cylinder for a simple, non-condensing engine installation.

Machinery

Diameter of wheel-shaft journal	$\frac{D}{2}$ plus ½ inch to 1 inch
Diameter of cross-head pin	$\frac{D}{4}$ plus ¼ inch
Diameter of crank-pin	$\frac{D}{4}$ plus ⅜ inch
Diameter of piston-rod	$\frac{D}{4}$

Steam lines

Diameter of main steam line	$\frac{D}{3}$
Diameter of branch steam lines	$\frac{D}{4}$
Diameter of main exhaust line	$\frac{D}{2}$
Diameter of branch exhaust lines	$\frac{D}{4}$ plus 1 inch

Boiler-feed lines

One to two boilers	1½-inch pipe
Three boilers	2 -inch pipe
Four to five boilers	2½-inch pipe
Six boilers	3 -inch pipe
Seven boilers	3½-inch pipe
The branch line to each boiler and for the "Snowden" heater	1¼-inch pipe

Paddle-wheel

Outside diameter equals 3 strokes (plus or minus)

Diameter	Number of arms
14 feet	10 to 12
15 to 16 feet	13
18 feet	14
20 to 22 feet	15
23 to 26 feet	16
28 to 30 feet	17 to 18

Wheel flanges

Hub diameter	D
Outside diameter	$3D$
Arm-pocket depth	D
Wedge room, large shafts	1¼ inches
Wedge room, small shafts	1 inch

Pitmans

For towboats, length center to center	4½ to 5 strokes
For packets, length center to center	3¾ strokes, or more
Cross-section at middle	$(D+1)^2$; also D^2

Cylinder beams (wood)

Width	D plus 1 inch
Depth at transom	1/8 of wheel diameter
Distance between beams..................................	$D + 3$, when D is less than 22 inches
Distance between beams..................................	$D + 2$, when D is over 22 inches

Hog-chain braces (wood)

Main braces	$\frac{D}{2}$
Relief braces (average)	8 inches square
Transverse and longitudinal braces below the boiler deck..	1 inch lighter than the above

While the list is not complete and while the dimensions derived were increased or decreased to suit the notion of the individual builder or operator, their performance indicates that they satisfactorily served the purpose for which they were intended.

The terms used to designate the hull scantlings of that time are indicated in Fig. 2.

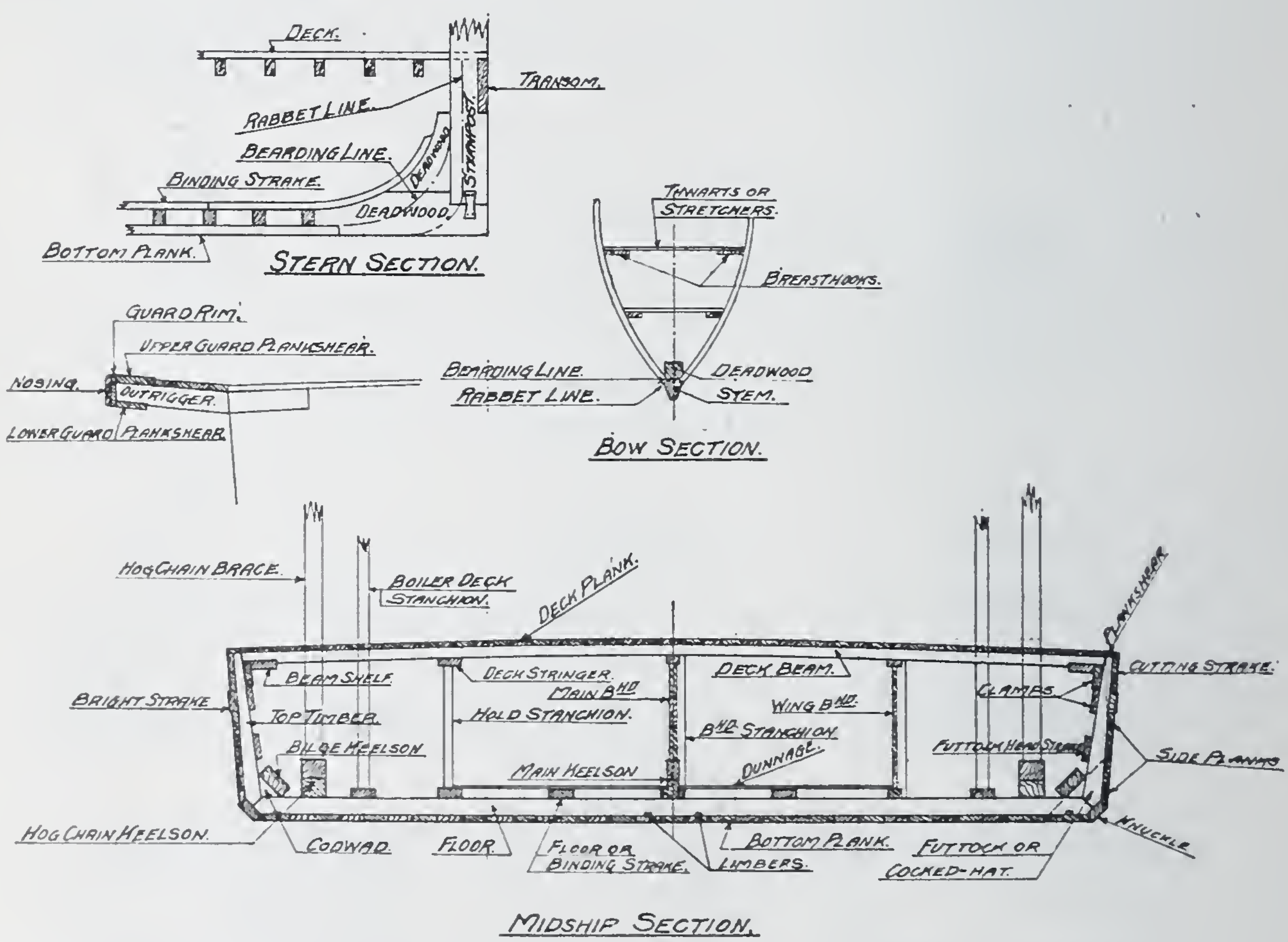


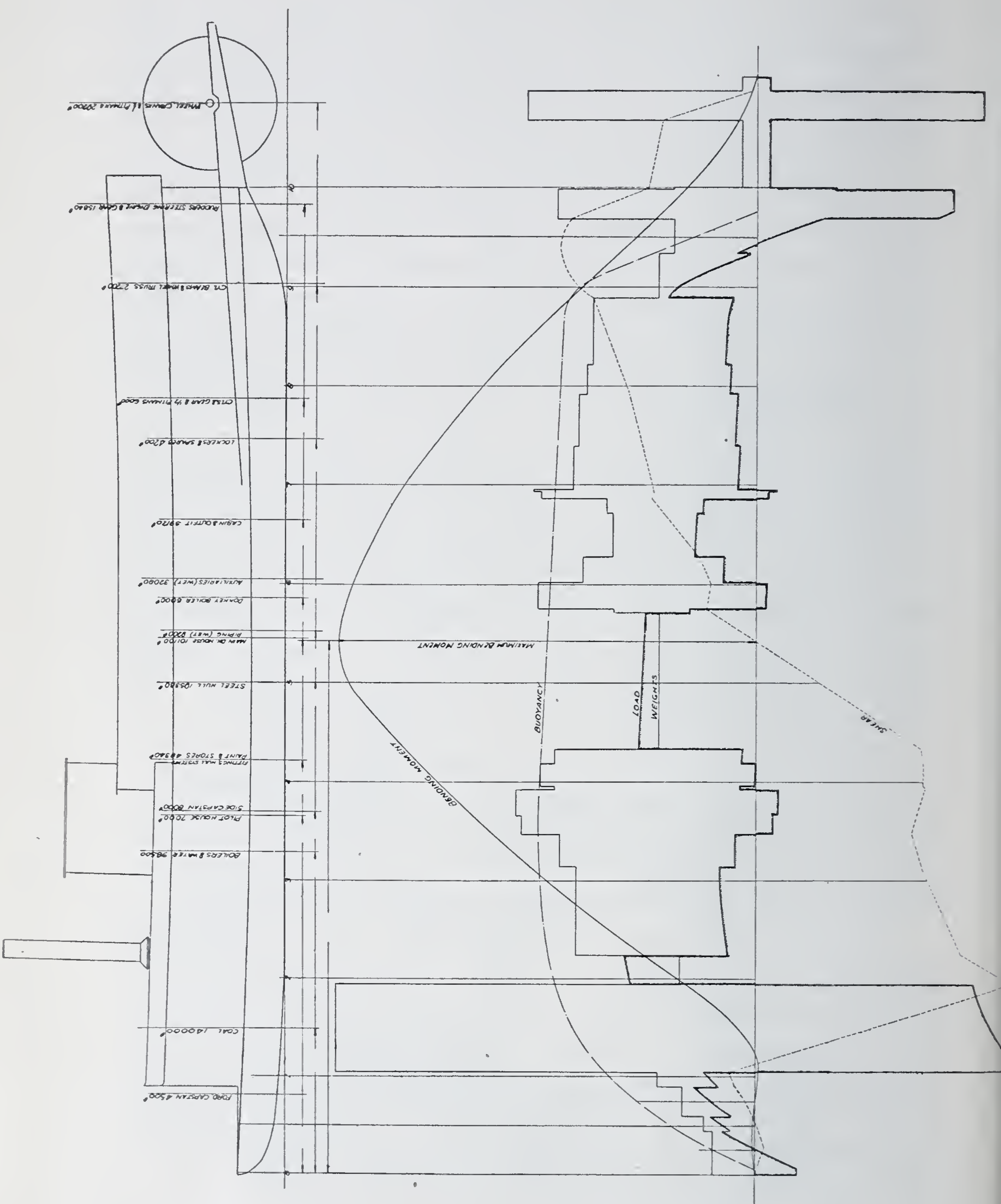
Fig. 2. Nomenclature at Beginning of Twentieth Century.

Considering a towboat of the stern-wheel type, we find that in the early days the unimproved condition of practically all of the navigable streams required that towboats be capable of operating on shoal water as much as the seasonal conditions would permit. As a consequence, the details in every department of the vessel had to be subordinated to that end. The details of the hull, the living quarters, and particularly the deck and propelling machinery, were consistently developed along special lines. One outstanding exception which failed to meet the requirements for light weight was the type of boiler employed. This well known boiler, whose parent was the "Lancashire" boiler, the surplus weight of which was overcome to an extent by "under-boilering," was used to some extent as an expedient, in that it afforded (1) a large water volume with its stored-up thermal energy to provide for those short periods of time when a large demand for steam was necessary, as when full stroking; (2) a large steam liberating area, and (3) a steam space that was in keeping with the demands of the large-diameter, long-stroke propelling engines. It also played two other decidedly interesting parts, in that it permitted a desirable distribution of its weight on the shallow hull structure, and, due to its weight, furnished the necessary counterbalance to offset the weight of the overhung wheel assembly at the stern to permit of trimming the boat.

Ordinarily, hulls of steel are framed transversely, although they are occasionally framed longitudinally and sometimes as a combination of both methods. As a matter of fact, a number of the first hulls to be built of metal for river service were framed on the longitudinal principle, and antedate the use for ocean marine service.

The bow forms are of two kinds—the model and the scow. Departures from these forms are merely modifications, as found, for instance, in the so-called "spoon" and "dead-rise" bows. In the model form, the head beam or forward transom is built "square" at the main-deck level to facilitate contact with barges and for the erection of knees, on deck, to increase the deck height for contact with barges when they are in "light" condition. In the scow form, a "square" head beam is presupposed.

The stern of the hull (still referring to a boat of the stern-wheel type) is always made as full as possible, consistent with the necessity


MAXIMUM BENDING MOMENT
BENDING MOMENT
BUOYANCY
LOAD
WEIGHTS
SHEAR

for supporting the wheel assembly and the desire to dispose effectively of the volume of water displaced by the paddle-wheel, as when backing.

Formerly, skegs were formed on the stern rake for the attachment of the rudders. Rudders so attached were of the unbalanced type, but a simple form of stern has been generally adopted, due to (1) a desire for balanced rudders which permitted presenting greater area to the wheel stream and the obtaining of greater reactions with the attending increase in ability to maneuver, particularly when flanking; and (2) the desire to remove the protruding skegs as obstructions to the free passage of the wheel stream to prevent the water from "piling" between the wheel and the hull, as when backing.

The "dead flat," or section of the hull between the formed bow and the stern, is invariably found to have a midship coefficient slightly less than unity.

Divisions of the hull, as a whole, are formed by means of longitudinal and transverse bulkheads and trusses. The former, as a rule, are made either water-tight or oil-tight and both are considerations for strength and stiffness.

Fig. 3 indicates the method of determining the stresses in a vessel of the type we are discussing. The curves of load, shear, and moment are determined in the order named by integrating the plotted curves of weight and buoyancy. By a careful distribution of the deck weights an accurate value for the bending moment and its location may be obtained.

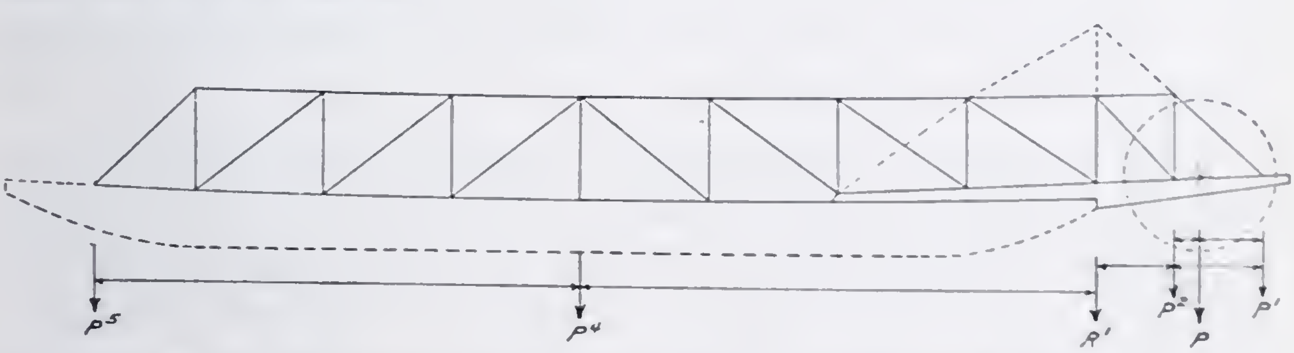


Fig. 4. Distribution of Load in Longitudinal Deck Trusses.

Fig. 4 presents the assumptions used in determining the forces and the reactions for the construction of a force polygon for the longitudinal deck truss. The force P is taken as twice the total reaction of all weights and forces at the pillow-block, and is distributed

proportionately between the nearest panel points. Then, with the reaction established at the transom, counterbalancing forces are located at the middle and the extreme end of the truss with intensities inversely as their distance from the reaction.

For the structure of the particular case we are citing, the fiber stress for the hull alone was under 8000 pounds and, considering the hull and the upper chord of the deck truss, it was under 7000 pounds. For the cylinder or wheel beams, considering only the outboard end, plus the jockey beam, one-half of the wheel and one-half of a pitman, plus the weight of a crank, and a crank reaction, the fiber stress was 7700 pounds.

In the absence of machinery on the upper or boiler deck, or other localized weight, the deck-house, or superstructure, is constructed of very light scantlings to provide for the weights associated with the crew's accommodation and the pilot house, and for protection from the weather. Special provision for strength is made, however, in the way of a coal-bunker and for the rudder assembly at the stern.

By way of indicating the care and judgment to be used in placing the machinery and other weights aboard a vessel for the conservation of strength and to assure a proper condition of trim, we digress for a moment.

When we speak of a ship, or a vessel, or a boat, we naturally think in terms of a fluid as the buoyant or supporting medium. In the case of aircraft, the supporting medium is the atmosphere. When it is a ship or vessel navigating on the surface of the earth the supporting medium is the water.

The supporting value of water, unlike the supporting value of the land, is fairly constant, varying only in slight degree throughout the "seven seas" in which the water is salt, and imperceptibly when the water is fresh. The support, however, of a vessel or structure afloat is a far more difficult problem than the support of a structure ashore, for the reason that the supporting medium is a yielding liquid having almost perfect fluidity, so that the slightest disturbance of equilibrium causes a flow. In consequence, the form of the vessel, the distribution and relative location of the fixed weight and such movable and usable weights as cargo, ballast, and fuel demand careful

consideration to justify the predetermined draft and trim. In addition, water-borne structures, unlike structures ashore, may be freely moved either by means of self-contained power-plants or from outside sources. This comparison prompts a further comparison with respect to the completeness to be found aboard a river vessel. With the exception of elevators, which are offset by the propelling machinery, a modern river vessel will include all of those features considered essential to comfort and well-being as found in a modern hotel. For instance, a fire-proof steel structure, electric light, steam heat, running hot and cold water which has been filtered and made potable, ventilation and intercommunication, kitchen and dining-room equipment, plumbing, laundry, and refrigeration; with floor coverings, furniture, bedding, napery, and china of the finest; as well as a system of fire protection and life-saving equipment. The more important equipment is subject to a searching examination by authorized officials at any time, and is continually under the control of licensed attendants.

Passing from the consideration of the stern-wheel boat, we have for consideration a boat of the propeller type. Here we find that the draft of the vessel is not influenced by the necessity for maintaining uniform depth of immersion, as is the case with the radial paddle-wheel with its fixed buckets. On the contrary, we are confronted with the problem of maintaining the full immersion of the propelling medium. It thus becomes necessary to provide for the reception of the upper portion of the propeller within the hull structure and to provide further for an adequate supply of water. This is accomplished by chambering the stern portion of the hull, and the chamber must be effectively water sealed to exclude the atmosphere.

The framing, trussing, and bulkheading of the hull for this type of boat differ little from those of the hull for a stern-wheel boat. As a matter of fact the problem is less complicated, from an engineering standpoint, in that it is possible to construct the hull as a buoyant vessel having sufficient strength within its structure to withstand the static and dynamic stresses, without recourse to superimposed trussing or chaining above the main-deck level. It is necessary to limit the hull depth in a stern-wheel boat to obtain sufficient depth of girder for the wheel beams and clearance for the pitmans at the transom by reason of a fixed wheel diameter and bucket immersion, and conse-

quent inadequate freeboard condition. On the other hand, the hull depth of a tunnel boat is a matter of some choice, and permits of the use of the hull compartments for the advantageous installation of the boiler, machinery, and auxiliary equipment. Sufficient space is thus made available on the main deck for quartering the deck crew and for other purposes, thereby decreasing the area of superstructure presented as resistance to the wind. In addition, this type of boat affords a desirable after-deck space.

For the purpose of comparing the relative resistance of the superstructures to head and cross winds and the general features of construction herein referred to we submit Fig. 5-8,* which show towboats of the stern-wheel type and the tunnel type from designs by the author. The former is of 600 nominal horse-power, with a girder hull, and operates on a mean draft of 42 inches with 30 tons of fuel. The latter is of 700 nominal horse-power and operates on a mean draft of 60 inches with 40 tons of fuel. The former is propelled by steam; the latter by Diesel engines.

One other kind of vessel employing the tunnel type of stern is the self-propelled barge, in which the propelling machinery is located in the extreme after portion of the hull. The space forward and the hull compartments afford excellent opportunity for carrying either bulk or package freight. The location of the machinery in the after end provides for the submergence of the propellers when in either the loaded or light condition.

Vessels of this type, now in service, are powered solely for their own propulsion. By placing additional power aboard, they may, in addition to performing service as independent carriers, perform all of the service to be expected of a towboat and thereby add to their value as transports, thus permitting of the movement of freight in towed barges during seasonal peaks with a minimum of power equipment, and at other times the movement of barge lots for "way-point" delivery without "way-point" time loss.

Fig. 9 shows a stress diagram for a tunneled-stern barge.

The method employed in producing the "curve of moment" is identical with the one previously described. In this case we see the necessity for basing the longitudinal strength calculations on the most improbable condition of loading.

*Fig. 5-7 on folding plates following page 458.

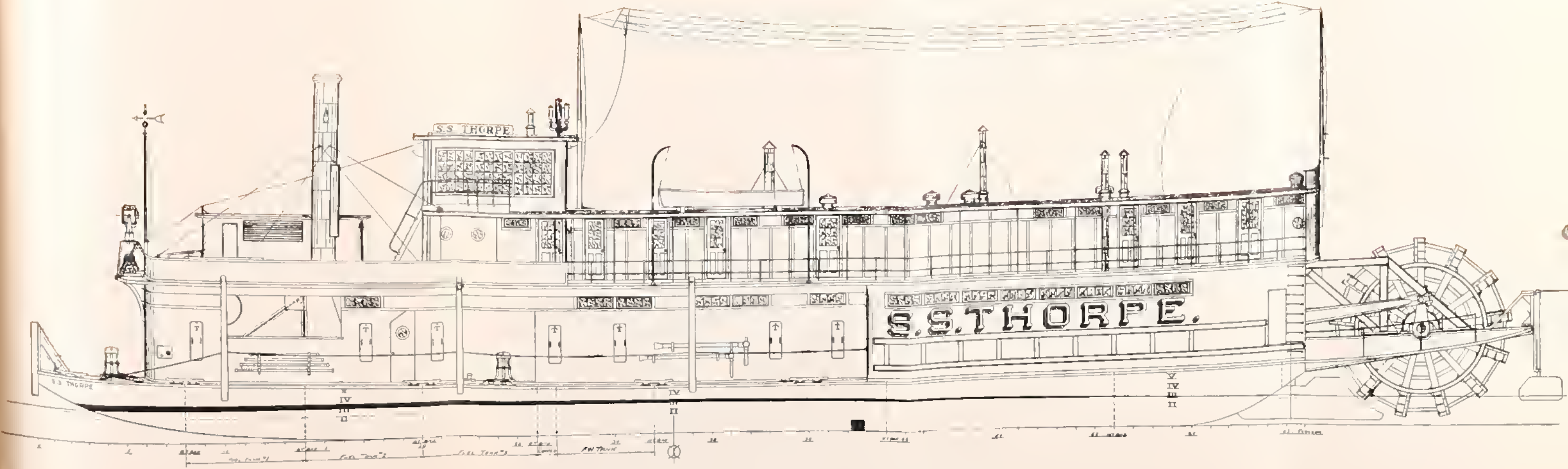


Fig. 5. Outboard Profile of Stern-Wheel Towboat for Upper Mississippi River.

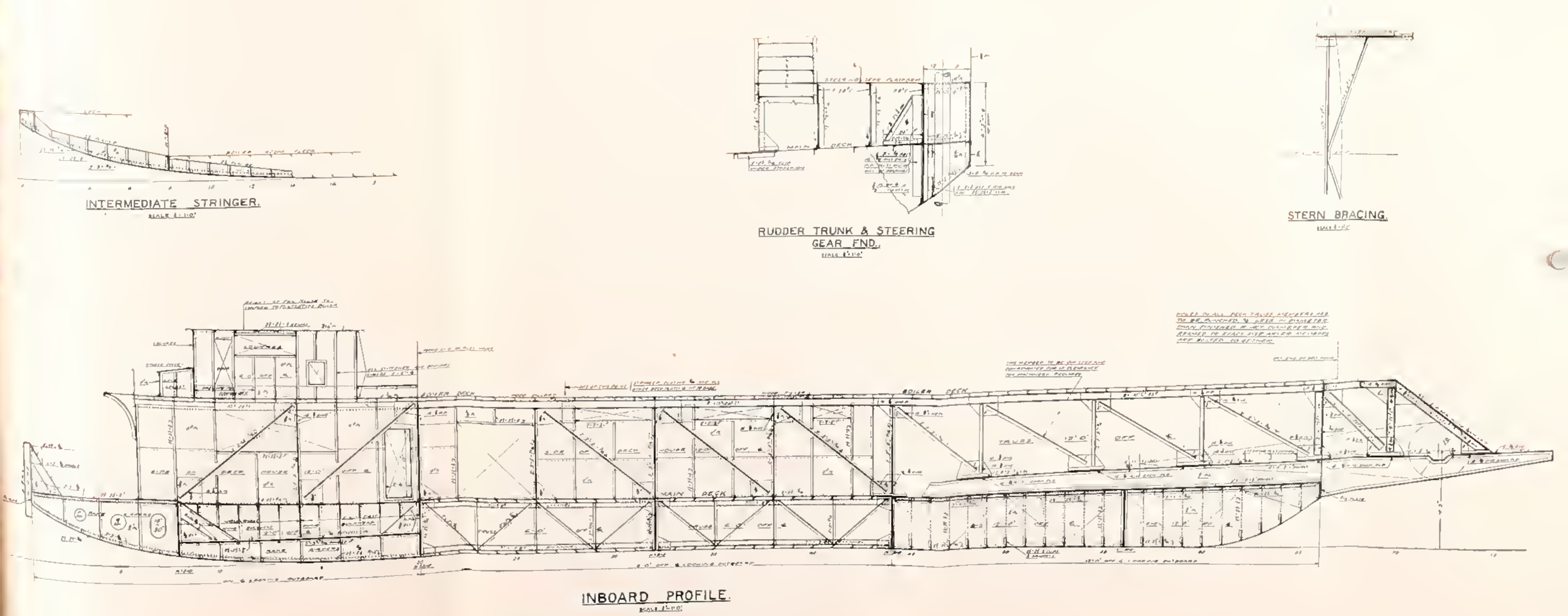
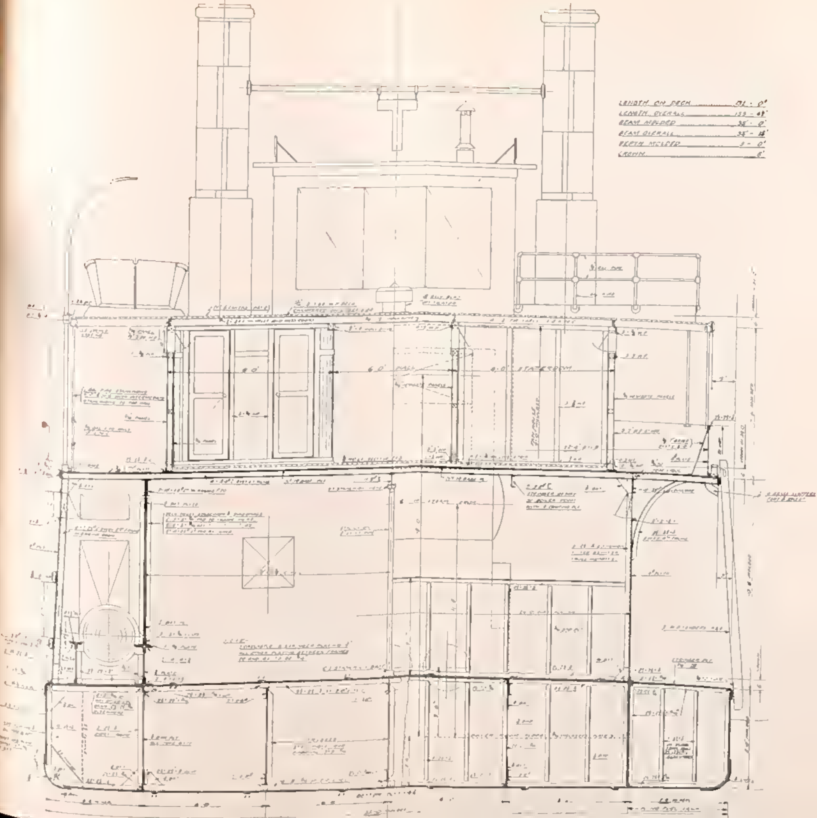


Fig. 6. Stern-Wheel Towboat for Upper Mississippi River.



LENGTH ON DECK
LENGTH OVERALL
BEAM MOLDED 35' - 0'
BEAM OVERALL
DEPTH MOLDED 9 - 0'
CROWN 6'
STATEROOM

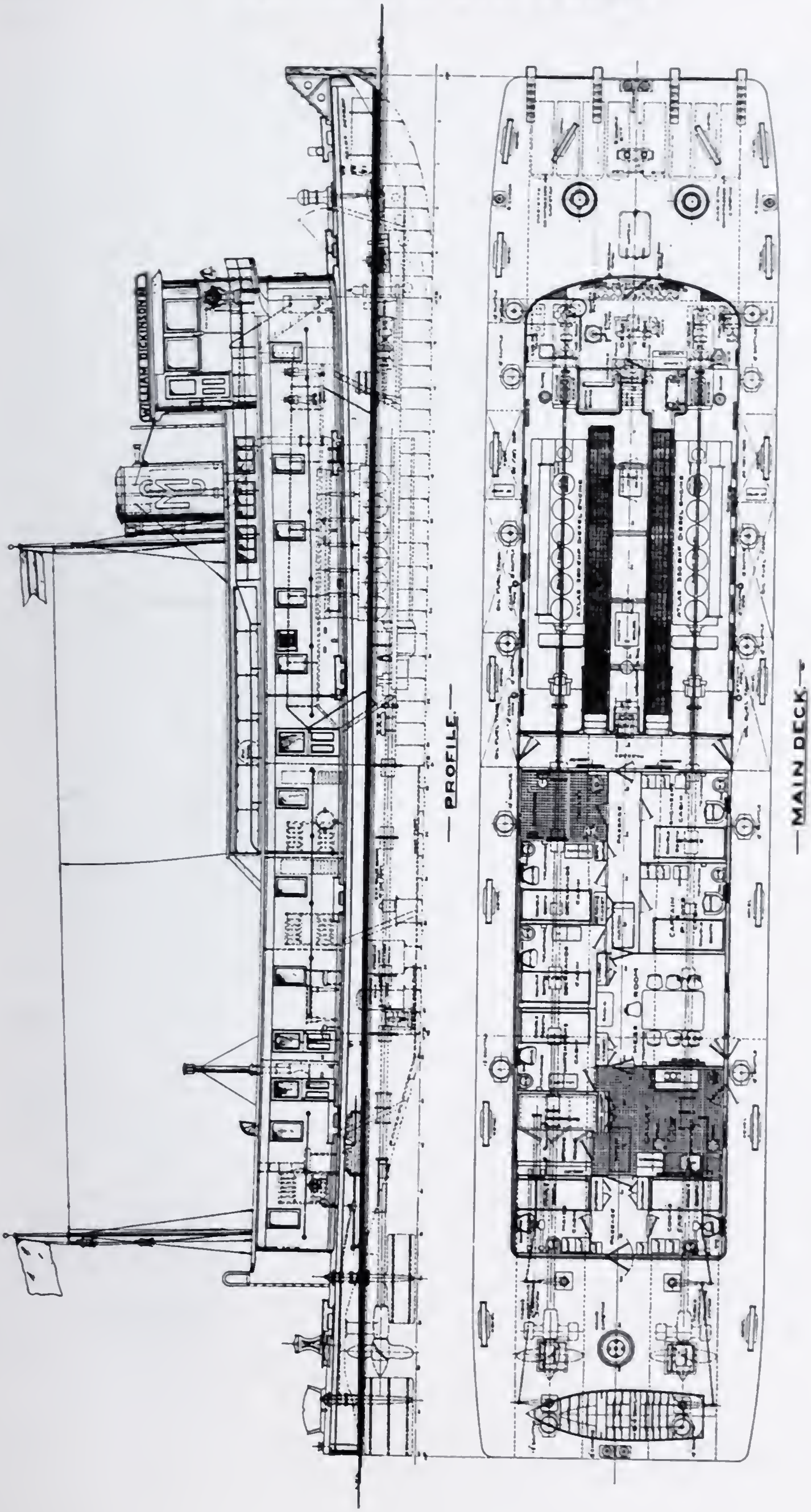
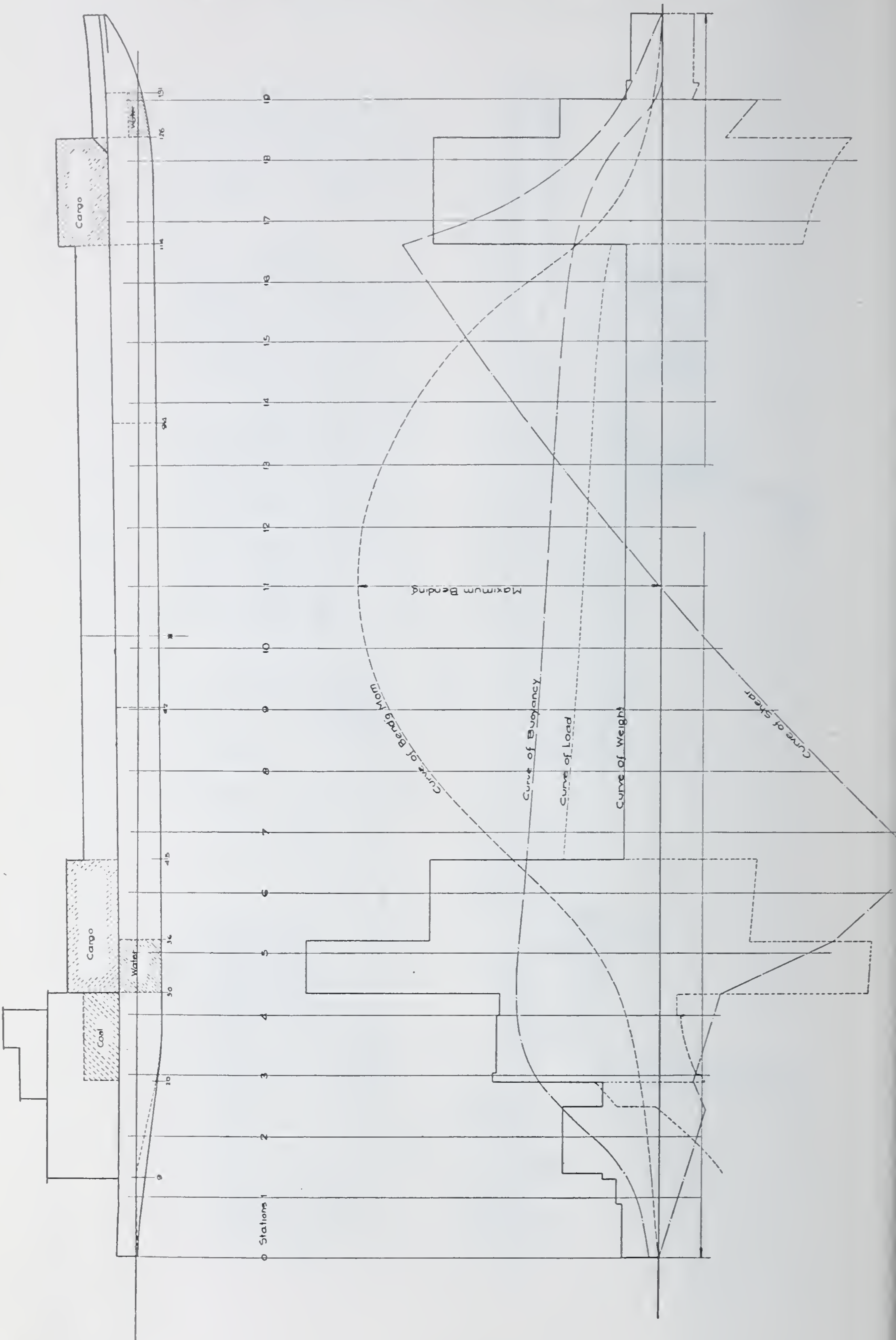


Fig. 8. General Arrangement of Lower Mississippi River Towboat.


Cargo
Water
Cargo
Water
Coal
Stations
Maximum Bending
Curve of Bending Mom
Curve of Buoyancy
Curve of Load
Curve of Weight
Curve of Shear

Space prevents detailed attention to the mechanical equipment aboard either type of boat. The matter has been ably presented from time to time by others. The tendency at present is towards the use of water-tube boilers for craft of the time-honored Mississippi River type. The oil-burning installations aboard the stern-wheel boats shown in Fig. 5 were of the water-tube type and included economizers, superheaters, induced draft apparatus, and preheated air.

The tendency with respect to the engine-room auxiliaries is towards the more efficient and suitable units employed in ocean marine service. The deck machinery, however, by reason of the special service required, is distinctive in type and, while marked improvement in design has been made, it bids fair to remain as a lasting memorial to the pioneer days.

The main machinery for propeller drives permits of far greater choice than in the case of paddle-wheel drives. Propellers may be driven directly by simple or compound reciprocating steam-engines, Diesel engines, steam-turbines through gearing; or, indirectly, by electric motors from current generated by any of the aforementioned prime movers.

In the case of the stern-wheel boat, the usual method—except in the smaller powers where gear and motor drives may be used to some advantage—is to deliver the engine power to the shaft of the necessarily slow-moving, overhung paddle-wheel by means of the twin, simple or tandem compound, horizontal, direct-connected, long-stroke reciprocating engine. Stern-wheel towboats with such engines have always, without exception, been burdened with main engine weights from two to three times that which would be necessary if it were possible to operate them at an acceptable piston speed of, say, 600 feet a minute. This is quite obvious when it is realized that the effectiveness of the paddle-wheel is dependent on peripheral speeds that fix the engine speed at from 200 feet as a minimum to 250 feet as a maximum. But, to the credit of those responsible for the arrangement, it may be stated that a more acceptable method for operating a stern-wheel boat has not yet been devised.

There are almost as many types of rudders as there are types of vessels. Even the highest authorities are at variance regarding the best form of rudder. Of late, however, considerable progress has been

made in rudder design to reduce resistance and to give a vessel greater turning ability with smaller angles of helm.

In the stern-wheel boat, the rudders are placed at the extreme after end of the hull. Those of the balanced type extend forward under the stern of the hull, and both the balanced and unbalanced types extend under a portion of the wheel. They are arranged with very close clearances to prevent their becoming jammed with debris and to form an effective dam in the path of the wheel stream when placed at an angle.

The passage of a body through a liquid presupposes a cross-sectional displacement of liquid equal to the area of the immersed section of the body. It also presupposes the refilling of the space at the rear of the body caused by its passage. Otherwise, the dynamic pressure set up by reason of the unbalanced hydraulic condition would seriously impede the progress of the body. If we now call this body the hull of a river boat, we can see that the volume of water required to fill the space or cavity at the stern is represented by the area of the immersed section, and the distance which it progresses through the water. Thus we find a zone of water following in the direction of the hull's motion, the direction of which is opposite to the direction imparted to it by the paddle-wheel. This zone of water is termed the wake and its speed is expressed as a fraction of the speed of the boat.

Information as to the value of the speed of the wake for a river boat is scanty and it therefore becomes necessary to assume a value, which may be taken as 20 per cent. of the velocity of the boat. In this wake, the stern paddle-wheels and screw propellers operate and the rudders function. The result is a gain for stern paddle-wheels and screw propellers when propelling the boat ahead and a loss when propelling the boat astern. In the case of side paddle-wheels the wake has no effect on the paddle-wheels.

By reason of the rudders being located within the zone of the wake, they are not as effective in steering as would otherwise be the case. In consequence, from the operation of the stern-wheel boat, it was soon found possible to produce greater rudder reactions by reversing the paddle-wheel to direct a high-velocity wheel-stream current against the rudders. The artificial current set up in this manner is equivalent to increasing the wake fraction to a value greater than unity, and this counteracts the influence of the natural current of the

stream relative to the hull at the stern. Such a procedure is what is known as flanking. It permits of the movement of the stern of the boat, to port or starboard, either when the boat is still or when under way.

While it is true that the reversing of the paddle-wheel acts to retard the forward progress of the boat and its tow during the time of flanking, the fact that such large capacity tows as were previously mentioned can be safely navigated around bends and through bridges with safety is compensation in full for the slight loss of headway occasioned. However, realizing that the full steering value of the rudders under the stern of a stern-wheel boat could not be obtained (since the rudders were located on the up-stream or suction face of the wheel and in the wake of the hull) numerous boats have been fitted with "monkey" or auxiliary rudders at the down-stream or discharge face of the wheel to supplement the action of the main rudders. Such an arrangement of rudders is shown in Fig. 5.

With the introduction of the twin-screw tunnel boat on the rivers several decades ago it was suggested that it would be only a matter of time until this type would supersede the stern-wheel boat; but it was early found that one of the two primary prerequisites for the successful operation of a river towboat was sadly lacking. This was the inability of a tunnel boat, as then built, to "back on a straight rudder" or maneuver itself and a tow with the same facility as a stern-wheel boat.

In the days succeeding the advent of this tunnel boat, numerous attempts were made to better its maneuvering ability by modifying the form of the stern and arranging the rudders in relation to the propellers. As a result, an "interlocking" arrangement of rudders as shown in Fig. 10 was considered to be the most effective. In this arrangement, two rudders are associated with each propeller. The rudder placed aft of each propeller is for steering, and the rudder placed forward of each propeller is for flanking. The former receives the greater wheel-stream current from the propelling face of the wheel, while the latter receives a lesser wheel-stream current from the backing face of the wheel. In addition, the effectiveness of the latter is further diminished by reason of its having a reduced area to present to the wheel-stream current due to interference of the stern tube.

Every well informed riverman was willing to admit the possibilities of building a tunneled-stern, propeller-type, river towboat that would be capable of equaling, or even exceeding the propelling ability of the stern-wheel boat; there were, however, very few who were willing to admit that the screw-propeller boat could approach the maneuvering or backing ability of the stern-wheel boat. This view was well taken, as we shall point out.

In the "interlocking" arrangement, all of the rudders were operated simultaneously by means of a centrally located steering-gear. It will thus be seen that when one of the propellers was operated in an ahead direction and the other propeller was operated in an astern direction in order to bring into action the twisting value of the propellers and thereby assist in altering the course, the rudders associated with only one propeller would be effective. As a matter of fact, their full effectiveness was reduced by the counteraction of the rudders associated with the other propeller. With the realization of this condition and after making a careful study of the possibilities for eliminating the conflicting rudder reactions, the author devised what is known as the "independent steering and handling system" which is now in service upon a dozen or more towboats of this type. Briefly, the system consists of operating the rudders associated with the starboard propeller independently from those associated with the port propeller, thereby permitting the rudders to be placed in the proper position with respect to the rotation of the propellers. As a result, the full benefit of the steering value from one side is obtained simultaneously with the flanking value of the other side, and the twisting value. In addition, it was found that the side-thrust of the propellers, by reason of the unbalanced condition set up by their counter rotation, was practically equal to the rudder reactions, and in harmony therewith, as a means to alter the course of the boat. It was further found that the inclined position of the rudders with respect to each other, due to the action of the propellers, created an unbalanced hydraulic condition at the sides of the boat by lowering the water-level at one side and raising it at the other side. This resulted in additional effective turning effort.

To summarize these values, we have:

1. Steering value of one set of rudders.
2. Flanking value of the other set of rudders.

3. Twisting value due to the spread of propellers.
4. Side-thrust of the propellers.
5. Side-thrust due to hydraulic head.

All of these features are in harmony with the desire to produce a maximum turning effort; and, be it noted, when the condition is set to produce the above, unlike the stern-wheel boat, only one-half of the power is expended in retarding the progress of the boat.

Fig. 10 shows the condition obtained due to the "interlocking" method of operating the rudders, and Fig. 11 shows the result of operating the rudders "independently."

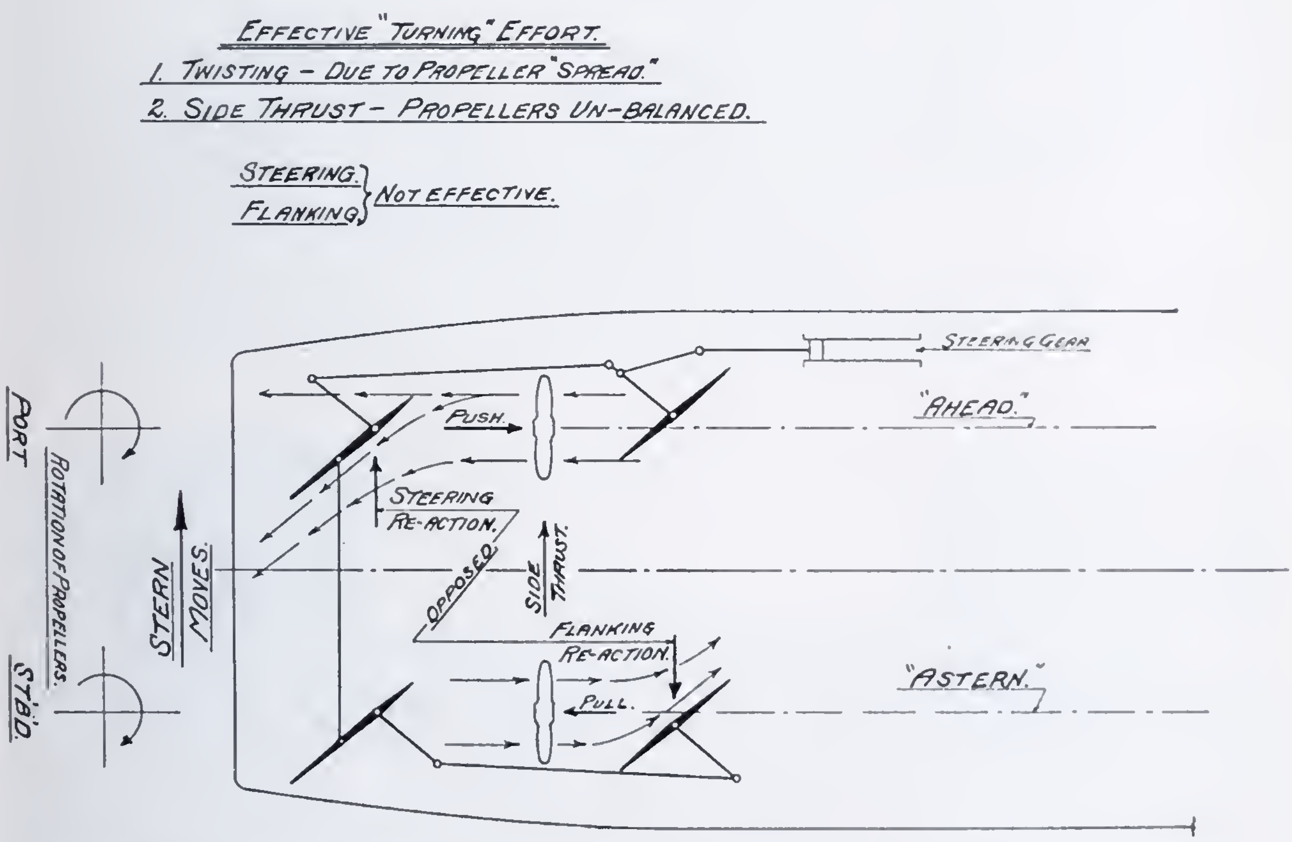


Fig. 10. Plan of Stern, Showing "Interlocking" Rudder Arrangement.

A graphic comparison of the rudder power for a boat of the stern-wheel type with both the interlocking and independent systems herein described appears in Fig. 12, which was prepared from the results of tests made in the United States Experimental Model Basin at Washington, D. C., in 1925 and published in the *Transactions of the Society of Naval Architects and Marine Engineers,* volume 33, page 63. In the curves for the stern-wheel boat, and the tunnel boat fitted with the interlocking method, it is to be noted that the angle of helm is 40 degrees, while for the independent method it is but 30

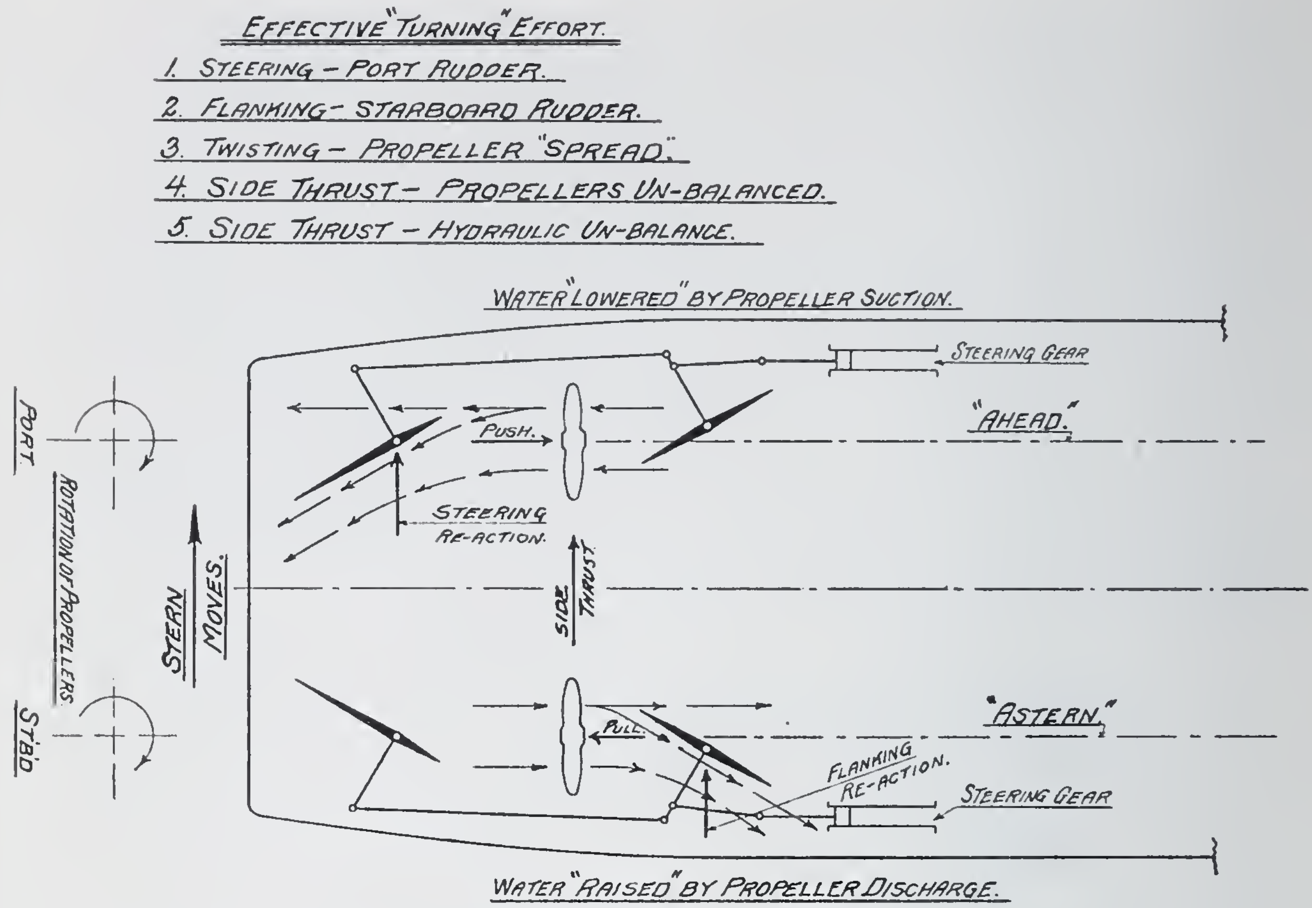


Fig. 11. Plan of Stern, Showing "Independent" Rudder Arrangement.

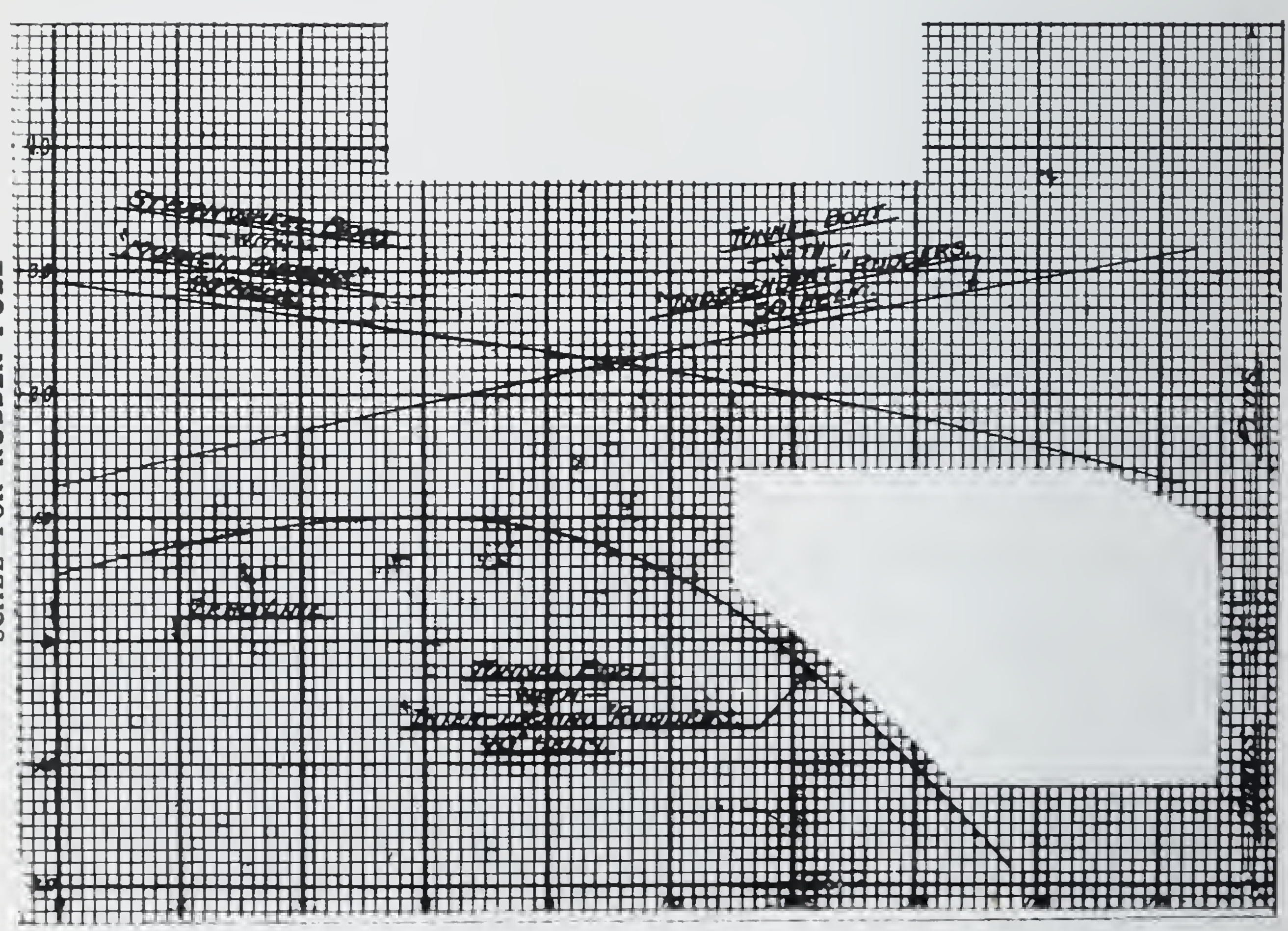


Fig. 12. Tests of Rudders.

degrees. In consequence, the independent method sets up less "drag" to retard the progress of the boat. It is also to be noted that at a certain speed of advance the curve of power for the interlocking method loses value and finally becomes negative, and that the independent method constantly increases in value as the speed increases. Also, that the stern-wheel towboat has the greatest ability to maneuver when the speed of advance is a minimum, the curve gradually declining as the speed of advance increases.

In a further effort to better the maneuvering ability of the tunnel-type boat, attention has also been directed to the form of the after body. For the most part, in the earlier constructions, a long, low, sweeping, stern rake was used. In this rake, long, rounded, inclined tunnels were formed. The result was an expensive construction that interfered not only with the free flow of water to and from the propellers, but added resistance to the lateral movement of the stern to be overcome by the rudders.

As a means for overcoming both of these undesirable features the open type of stern shown in Fig. 13 has been built, in which the

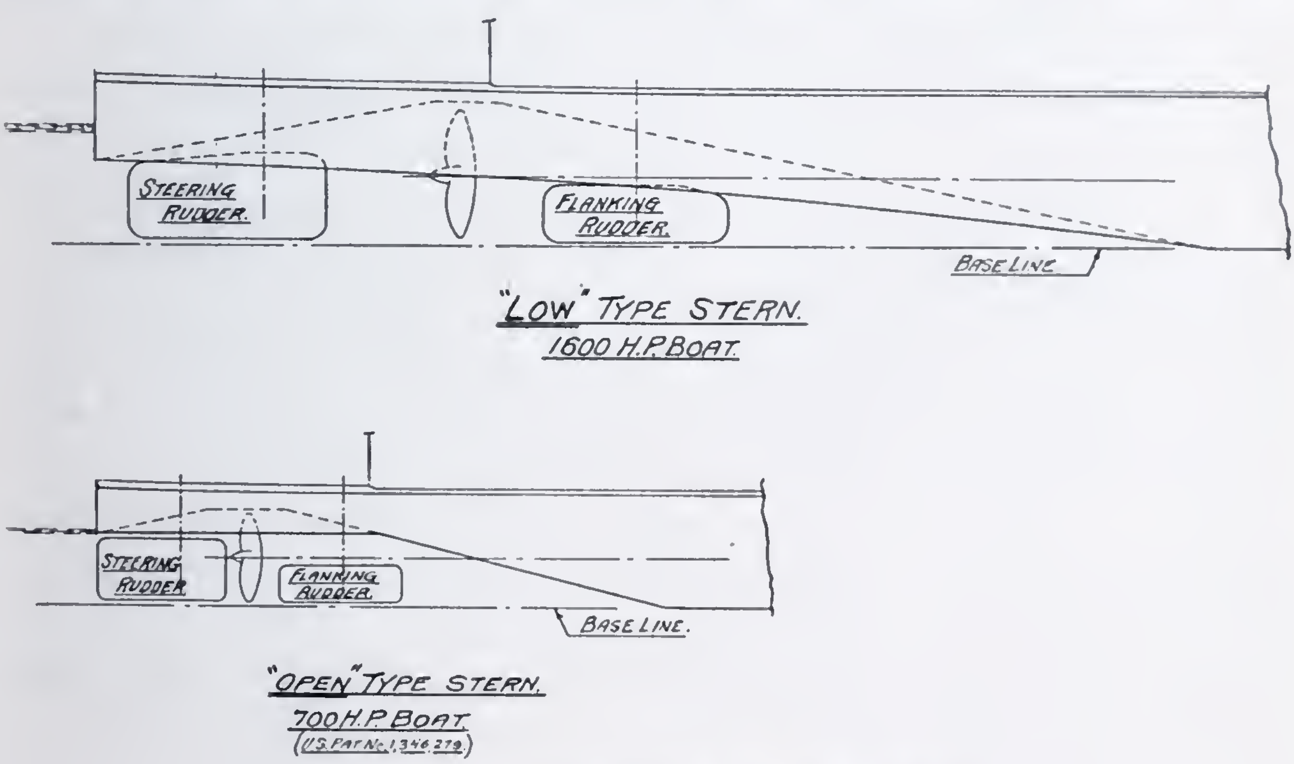


Fig. 13. Comparison of Tunnel Sterns.

tunnels are formed as continuations of the stern rake and the centerboard effect of the old type of stern has been done away with, thus adding to the effectiveness of the propellers and permitting the stern to move freely from side to side.

Having examined as briefly and intimately as possible the considerations of resistance, power, and maneuverability for the several types of river boats, we pause to examine the possibilities for the further development of boats for river service.

As a type, the stern-wheel boat, like the poor, has always been with us and, aside from refinements in its structure and its power-plant, it bids fair to continue as a type. This last statement also applies with equal force to the tunnel boat. The same inherent features possessed by each of these types may be successfully incorporated in boats for services other than towing.

If we were to point out what would constitute further development and what salient features or departures from existing methods of towboat design could be brought about, it would be necessary as a first consideration to speak in terms of resistance—bearing in mind both the existing condition of the rivers and the possible improvement—and then in terms of power and structure.

In the consideration of any of these factors it is quite evident that an effort should be made to retain the desirable features of existing methods and eliminate as many of the undesirable as possible.

As far as river towboats are concerned, they, like all other power producing or consuming units, fall short in delivering an output that corresponds to the input. The method of generating and converting power aboard ships has received a great deal of attention, looking towards the betterment of economy, reliability, and adaptability for service conditions, and research and refinement have achieved a high state of efficiency. Refinements have been introduced to lessen resistance, to afford greater security and comfort, to reduce vibration, to minimize cost and weight, and to increase seaworthiness and maneuverability; but the use of propellers and paddle-wheels for applying the power to the water has remained virtually unchanged since the days when "plus fours" were worn with golf clubs rather than with walking sticks.

The knowledge of a disease presupposes the knowledge of a cure, if it is to be alleviated. Rankine's statement that the best method of propulsion is the one which displaces the largest volume of water at the lowest velocity has never been applied to the propulsion of water-borne vessels in the light of present knowledge bearing upon the hydraulic and naval principles involved. In substantiation of this

statement we point first, to the high development of the centrifugal air-compressor by the General Electric Company; and, second, to the well known fact that the impulse or reaction of a jet issuing from an orifice is double the pressure on the area of the orifice.

Consider, if you will, a centrifugal type of air-compressor having an efficiency of upwards of 70 per cent. compressing the abundant, universal, and costless atmosphere to a pressure slightly in excess of the pressure corresponding to the draft of the vessel. Now consider a long, shallow, rectangular orifice in which 96 per cent. of the energy is available,* and then recall the previously stated overall efficiencies of 10 to 26 per cent. for the paddle-wheel boat and 40 per cent. for the screw-propeller boat; and understand that "the old gray mare" has evidently been hitched to the wrong treadmill.

True, the principle of jet propulsion has been tried; but with pressures of 2500 pounds per square inch, and with nozzles ⅝ inch in diameter, and not to fulfil the conditions laid down by Rankine.

Having named the disease, let us name a few of the curative advantages such a propulsion system would effect:

1. The lack of appendages, such as rudders, propellers, stern frame, stern tubes, stern bearings or struts to restrict the progress through the water.
2. The ability to maneuver, ahead, astern, or sidewise.
3. The elimination of propeller vibration; the elimination of repair, lubrication, and periodic inspection of submerged parts; the elimination of the nightmare of a lost or damaged propeller; the gain in cargo space; and the reduction in draft and in cost.

Eventually, we believe, such a means of propulsion will be utilized not only for marine purposes, but for eliminating the high-velocity, resistance-creating air stream issuing from the makeshift, man-killing propellers used on aircraft.

As a further possibility for meeting the demand for power on the restricted navigable depths obtaining on those rivers which have unfortunately not been thoroughly improved, we point out the possibility of building a towboat of greater power and of shallower draft than could be consistently accomplished in either the stern-wheel or

*Treatise on Hydraulics, by Mansfield Merriman. Ed. 10, 1916, p. 134.

tunnel types, and this without violation of the laws either of propulsion or of river navigation.

This possibility is the towboat on which are installed a pair of side-wheels in addition to a stern wheel. The side-wheels should be independently driven by means of reversing geared turbines, similar to those manufactured by the Westinghouse Electric and Manufacturing Company and recently installed on a Great Lakes tug. The operation of the side-wheels should preferably be arranged for pilot-house control to permit of ordinary maneuvering being accomplished by their opposed reactions. The stern wheel should be driven in the conventional manner and controlled from the engine-room.

Though such a towboat has never been built, the association of side-wheels with a stern wheel on the same hull does not present any engineering difficulties and recommends itself particularly for present service on the Missouri River.

In bringing the paper to a close it appears inconsistent that so much reference should be made to the design and operation and nothing said about the outstanding facilities of the boat yards to carry out the design and thereby make possible the operation.

The river boat yards are prepared to meet any emergency with high-class engineering and skilful shipwright organizations that have at their disposal the most modern and efficient machine-tools and equipment necessary to produce economically not only the hulls and machinery, but all of the appurtenant structure and outfit entering into the construction of marine equipment. For instance, one of the yards, during recent times when the Satanic caldron was boiling, directed its energy to furnishing fabricated ship material to the Hog Island activity to help enrich the pottage. Another engaged in the more peaceful pursuit of duplicating the workmanship of that type of craft on which Wall Street "tax-exempters" entertain their soul mates over the week-ends. In another case, two under-water stern plates, injured in launching, were formed, punched, sheared, and made ready by the time the vessel was dry-docked, and made to fit in a manner that would make a one-piece bathing suit blush. There is yet another yard, where not only some of the largest and most powerful boats have been built, but where any boat may be hauled out on one of the most modern marine railways in existence.

DISCUSSION

J. A. DENT, *Chairman:** I want to thank Mr. Tarn for this very comprehensive and illuminating paper. I only wish that I had had the paper before I went on the inspection trip this afternoon. When I went on those boats that were shown to us through the courtesy of the Carnegie Steel Company, the Jones & Laughlin Steel Corporation, and the Keystone Sand and Supply Company, I would have had a better background for what I saw.

I am going to call on Mr. V. B. Edwards, who will speak with special reference to boilers.

V. B. EDWARDS:† The author of the paper is to be congratulated on offering a paper so valuable and instructive in connection with one of the very important industrial activities in the Pittsburgh district. There is probably no other place in this country where the operation of shipping is so closely identified with industry.

Locally, there has been a great increase in the use of river transportation by industrial concerns handling raw materials in bulk. To a lesser extent semi-finished products are handled by river between plants, and to a large extent finished products are handled to the middle west, south and southwest by commercial river transportation companies as well as by river fleets of the industries.

It has been suggested that my remarks and comments be especially directed to a consideration of boilers as used in river towboats. Practically every one familiar with river towboats immediately thinks of the Mississippi River type boilers, which consist of one or more shells 38 to 42 inches in diameter, 20 to 30 feet long, with from two to ten tubes, carrying a steam pressure of from 200 to 230 pounds. The requirements of the United States Steamboat Inspection Department have limited the thickness of boiler shells for this type of boiler, and this in turn limited the diameter of the shell to be used for a given pressure. To provide for increased boiler horse power an increased number of shells are installed, joined by a steam-drum and two mud-drums common to all the shells.

Too much credit can not be given to those who originally developed this type of boiler. It was used in connection with simple high-

*Professor of Mechanical Engineering, University of Pittsburgh, Pittsburgh.
†Vice-President and Chief Engineer, Dravo Contracting Co., Pittsburgh.

pressure steam-engines and drew its water-supply from rivers heavily laden with silt, and the operation of the early steamboats under low-water conditions increased the amount of mud entering the boilers. Over a long period of years this type of boiler has proved satisfactory because, with frequent blowing down and occasional cleaning, it has successfully met this operating condition. There have always been, however, relatively heavy maintenance and repair charges, due to the operating conditions cited above, and in our local rivers there has been an increased maintenance cost due to the heavy acid content of the water.

During recent years owners have become more and more concerned with the economical operation of their towboats. The first step to improve the mechanical equipment involved the main engines, which were made compound condensing without any change in the boiler installation, except that less boiler power was required due to the economy effected in steam consumption. The use of condensate as boiler feed-water resulted in savings in boiler maintenance, although there was still a large amount of raw river water used for boiler make-up.

Modern cost-keeping methods as applied to river transportation problems concern themselves mainly with two principal considerations:

1. The cost per ton-mile for up-stream and for down-stream towing.
2. The cost per operating hour for the towboat. This has for a background, an operating efficiency, measuring the number of hours of useful work performed per month or per year; the initial investment on which interest, depreciation, and insurance are charged; and all charges for operation, maintenance, and repair.

Comparing the fuel requirement of a modern towboat with that of older types in terms of coal consumption, we find high-pressure non-condensing stern-wheel towboats using from six to eight pounds of coal per horse-power hour, the condensing type using from three to four pounds per horse-power hour, and the most modern type using less than 1½ pounds per horse-power hour. This modern towboat has fewer limitations as to type than any of its predecessors. Its fuel

consumption may be measured in terms of pounds of coal or pounds of oil per horse-power and its practical application will be governed by the requirements for power.

Considering towboats of from 1000 to 2000 horse-power, the owner can select from the following types:

- Propeller type, with triple-expansion or uniflow engines and water-tube boilers.
- Propeller type, with turbine-electric drive and water-tube boilers.
- Propeller type, with steam-turbines, reduction gearing, and water-tube boilers.
- Propeller type, with direct drive by Diesel engines.
- Propeller type, with electric drive, and Diesel engine generators for power.

Only a thorough analysis of the service requirements measured against estimated operating costs and initial investment or expenditure will determine the most suitable type of equipment. The use of stern-wheel towboats with slow-moving propelling engines, with comparatively long cut-off for uinform torque to stern-wheel cranks, can not be considered when economical fuel consumption is the basis of comparison.

For shallow-draft operations, such as the upper Mississippi or the Missouri River, certain advantages, in a side-wheel type of towboat, such as the use of feathering wheels, higher r.p.m of wheel and use of triple-expansion engines or geared turbines will make an economical installation.

Considering towboats of from 500 to 1000 horse-power, economical fuel consumption in steam equipment becomes more difficult to obtain and in many instances will result in prohibitive first cost. It is suggested that the selection be from the following types:

- Propeller type, with triple-expansion or uniflow engines, and water-tube boilers.
- Propeller type, with direct drive by Diesel engines.
- Propeller type, with electric drive and Diesel engine generators for power.
- Stern-wheel type, having modern engines with low steam rate, and water-tube boilers.

Stern-wheel type, with geared drive by Diesel engines.

Stern-wheel type, with electric drive and Diesel engine generators for power.

Draft requirements will usually dictate whether the stern-wheel or propeller type is to be used. It is to be noted that two towboats of 1000 horse-power each and able to operate on four-foot draft are now in contemplation for the Missouri River.

For towboats under 500 horse-power, satisfactory and practical operation will be obtained with any of the above types, but the most economical operation will be with either the propeller drive or the stern-wheel Diesel drive.

This discussion of the modern economical towboat serves to focus attention on the departure from the use of the Mississippi type fire-tube boiler, and the adoption of the marine type water-tube boiler for towboat use. For the most part, the boilers that have been used are of the cross-drum straight-tube type, with pressures from 250 to 300 pounds per square inch, and with superheat usually about 200 degrees.

Efficiencies in steamboat boilers of the Mississippi River type are usually 50 to 60 per cent., while marine water-tube boilers have an efficiency of 70 to 75 per cent. when with hand-fired coal installations, and 80 to 85 per cent. when burning oil.

Many installations of water-tube boilers on ocean ships have been made, providing furnace and fire-room arrangements so that either oil or coal can be used for fuel, and in some instances the owner has had in mind the possible use of pulverized coal. It should be mentioned that either stokers or pulverized coal will increase the boiler efficiency at least 10 per cent. above that which can be obtained with a hand-fired installation. River transportation companies running into New Orleans, where bunker oil can now be obtained for 55 cents a barrel, can effect considerable economy in operation by the use of oil for fuel.

With water-tube boilers, consideration can be given to the use of high temperature, high superheat, and high pressure. So far as is known there have been no towboat installations that have made use of high temperatures and high pressure to obtain additional economy. The practicability and economic value of using higher pressures and

temperatures have been clearly shown in power-plants on land, and particularly in modern central stations.

From a paper by J. H. King in *Transactions of the Society of Naval Architects and Marine Engineers,* volume 37, 1929, I quote figures from two tables, on page 171, showing Rankine cycle efficiencies and water rates.

Based on a constant gage-pressure of 250 pounds, 28.5 inches of vacuum, and varying superheat:

Pressure, pounds per square inch	Superheat, degrees F.	Total temperature	Rankine cycle efficiency, per cent.
250	0	406	31.90
250	50	456	32.18
250	100	506	32.42
250	150	556	32.70
250	200	606	33.01
250	250	656	33.32
250	300	706	33.70

Based on a constant temperature of 700 degrees F., 28.5 inches of vacuum, and varying pressure:

Pressure, pounds per square inch	Total temperature	Rankine cycle efficiency, per cent.
250	700	33.63
300	700	34.39
350	700	35.07
400	700	35.56
450	700	36.05
500	700	36.46
550	700	36.83
600	700	37.18

In actual practice these efficiencies are bettered by the application of the reheat and regenerative cycles.

Superheaters installed in marine water-tube boilers are usually of the inter-deck type, which is most suitable for high superheat. For low superheat up to 100 degrees, superheaters are preferably installed on top of the boiler. Ordinary river service involving lockings and

frequent landings results in varying quantities of steam passing through the superheaters, and to insure a sufficient quantity of steam flow through the superheaters at all times in order to prevent burning of superheater tubes, desuperheaters are usually installed. All the steam used by the auxiliaries passes through the superheater and is then desuperheated before passing to the saturated-steam auxiliaries.

Two considerations contribute very largely to the successful operation of a water-tube boiler.

1. Pure feed-water must be used. This requires that evaporators or distillers be provided in ample capacity to supply all make-up water, and it is important that there be a minimum use of non-condensing steam. This refers to the use of steam siphons or any other non-condensing auxiliary equipment.

2. The boilers must be kept free from oil. In selecting the propelling machinery as well as the auxiliary equipment, one of the important considerations is the selection of equipment that will require a minimum of lubricating oil, and for this reason the steam-turbine has given splendid results when used in connection with high superheats and water-tube boilers.

Considerable attention has been given to heat-recovery apparatus in connection with water-tube boilers, the means usually being either air heaters or economizers or both. This is particularly true with oil-burning furnaces. The benefit of recovering this heat in the gases is quite evident from the fact that a reduction of 40 degrees F. in uptake temperature is equivalent to an increase of one per cent. in efficiency. However, the cost of fuel may be so low that the net gain in efficiency and the resulting decrease in fuel consumption will not be warranted. Additional heating surface in the boiler may accomplish the same result, and eliminate the use of either economizers or air heaters. Recent sea-going installations have secured further economies by the use of electric auxiliary equipment, using steam-operated boiler feed-pumps as stand-by units. Recent river installations have had partial installations of electric auxiliaries.

All of the above has been written having in mind economical towboat operation, and there has been no attempt to deal with the many complicated problems connected with the design and construction of a modern towboat where propulsive efficiency, maneuvering

qualities, and a particular service must be combined with economical operation.

J. A. DENT, *Chairman:* Mr. H. G. Mueller is to discuss the uniflow engine as applied to towboats and dredges on inland waterways.

H. G. MUELLER:* The uniflow principle has for its object the elimination of one of the greatest losses in reciprocating steam-engines—initial condensation.

With the uniflow engine, the steam enters the cylinders at the ends, after passing through steam-jacketed heads, and, after cut-off and expansion have taken place, the steam is exhausted through ports arranged around the center of the cylinder, which are uncovered by the piston at the end of the stroke. The steam has, consequently, a flow in but one direction, hence the derivation of the phrase "uni-directional flow."

In the counterflow engine, the steam returns on its path to the end of the stroke, and is exhausted at the same end of the cylinder at which it enters. By this method, the comparatively cold expanded steam of considerable volume washes the cylinder walls and head during 50 to 75 per cent. of the return stroke, thereby cooling them to such an extent that the boiler steam, when it is again admitted, is cooled or condensed by coming in contact with the head and clearance spaces of the cylinder which have just been cooled by the expanded exhaust steam. It is this cooling effect that causes what is termed initial condensation, which is almost entirely eliminated in the uniflow engine, where the ends are kept hot and the center or exhaust belt cool.

It was to remedy this fundamental defect of the counterflow engine that successive expansion stages were resorted to, as in compound or triple-expansion engines. Superheating has also been employed to overcome the above mentioned difficulty; but the superheat is greatly diminished at or before the cut-off point by the counterflowing effect.

There are three uniflow cycles in common use, as shown in Fig. 14, in which the left-hand sketch depicts the original condensing

*Chief Engineer, Skinner Engine Co., Erie, Pa.

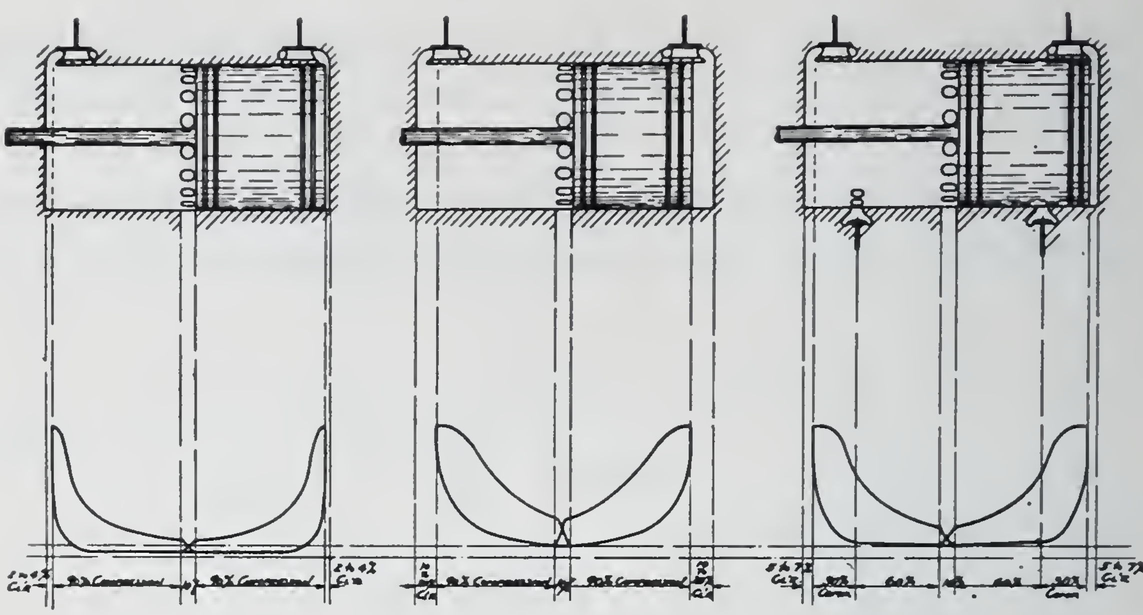


Fig. 14. Typical Cycles.

European uniflow indicator-card, in which compression begins as soon as the piston covers the central exhaust ports on its return stroke. Compression takes place, therefore, during 90 per cent. of the stroke, which, even with the small clearances used (two to four per cent.), does not cause it to mount above the initial pressure as long as the engine is operating condensing, with a fairly good vacuum, as shown in this indicator-diagram. The middle sketch shows the original non-condensing European indicator-card in which the compression also begins when the piston covers the central exhaust ports, and continues for 90 per cent. of the return stroke. This type requires large clearances (12 to 20 per cent.) to prevent the compression at the end of the compression stroke from exceeding the initial pressure. The large clearance necessitated by this design is very detrimental to steam economy. The right-hand sketch shows the non-condensing uniflow cycle as used in America. This four-valve type employs auxiliary exhaust valves which are closed on the expansion stroke, and opened on the compression stroke, delaying the compression rise for 60 to 70 per cent. of the stroke. A timed exhaust-valve located at the end of the stroke in the clearance volume is used by some builders. The Skinner uniflow, however, uses an exhaust-valve with ports located in the cylinder at the point where compression begins, and the timing of this compression is, therefore, accomplished by the piston covering these ports and eliminating the detrimental effect of the washing of the steam-jacketed heads with comparatively cold exhaust steam, which is the case where the auxiliary exhaust-valve is

located at the end of the stroke in the clearance volume. With this type of uniflow cycle, the clearances are reduced to five to seven per cent., with a corresponding improvement in steam economy, as compared to that obtained with the cylinder shown in the middle sketch. At the same time, a shorter cut-off is obtained for the same mean effective pressure, by reason of the gained area on the underside of the indicator-card, due to the delayed compression.

It is the first of these cycles, or that shown at the left in Fig. 14, in which we are primarily interested for marine application, as practically all marine engines run condensing. It should be noted that all of these cycles involve the combination of a long piston, with length equal to the stroke, less the length of the central exhaust ports, together with these ports, and steam-jacketed heads.

During 1929 the Skinner Engine Company contracted to build four three-cylinder, vertical, uniflow engines, each unit to drive and to be direct coupled to a screw propeller mounted in a tunnel, for two twin-screw ships—the *Tennessee* and the *Ohio*. The requirements were 800 shaft horse-power per screw at 170 r.p.m., and 1000 shaft horse-power per screw at 185 r.p.m. The steam conditions were 250 pounds gage at the throttle, 200 degrees F. superheat at the throttle, and 26 inches vacuum at the exhaust nozzle. The steam inlet valves used are the compensating-seat, steam-tight, double-beat, poppet-valve type, and the valve-gear is of the double-cam, shaft-reversing type.

Acceptance tests under a heavy penalty for failure to meet guarantees were run in accordance with the code of the American Society of Mechanical Engineers on the *Tennessee*, and the results obtained were as follows. The steam per indicated horse-power hour at the rated mean effective pressure was 9.3 pounds, obtained on two separate tests with the ship stationary and the bow against the bank of the river; and on a third test, under normal operating conditions, with the ship running up-stream, the economy was slightly better, showing 9.05 pounds. An underload test was run at 66 per cent. load, showing 8.7 pounds per indicated horse-power hour. An overload test at 135 per cent. load was also conducted, showing 10.5 pounds per indicated horse-power hour. Considering the average operating conditions with a steam rate of 9.05 pounds per indicated horse-power hour and an evaporation in the boiler under actual conditions of 13.5 pounds of

steam per pound of "Bunker C" fuel-oil, the fuel rate per indicated horse-power hour on each of the main units is 0.67 pound of oil. In view of the comparative simplicity of this installation, consisting of two three-cylinder engines direct coupled to propeller screws; their comparatively low initial cost; their maintained economies and low maintenance cost; their quick reversibility (five seconds from full forward to full reverse); their ability to develop power in reverse equal to that in forward with equal economy; their very low steam consumptions under maneuvering and partial load conditions; their greater overload capacity (full load requiring only eight to 10 per cent. cut-off); and the moderate steam conditions as compared with recent marine steam installations, together with low-cost boiler fuel, we feel that this type of prime mover has a considerable advantage over any other type so far developed.

The mechanical efficiency of these units is from 93 to 95 per cent., depending on the load conditions, and as this comprises the total loss from steam to the screw, the transmission, losses, and maintenance are extremely low.

The uniflow engine was first applied, in America, to stationary plants; and a typical longitudinal-vertical section through a horizontal single-cylinder engine is shown in Fig. 15. This development took place from 1910 to 1913, and included the development of poppet-valves and suitable valve-gear, for the inlet as well as for the

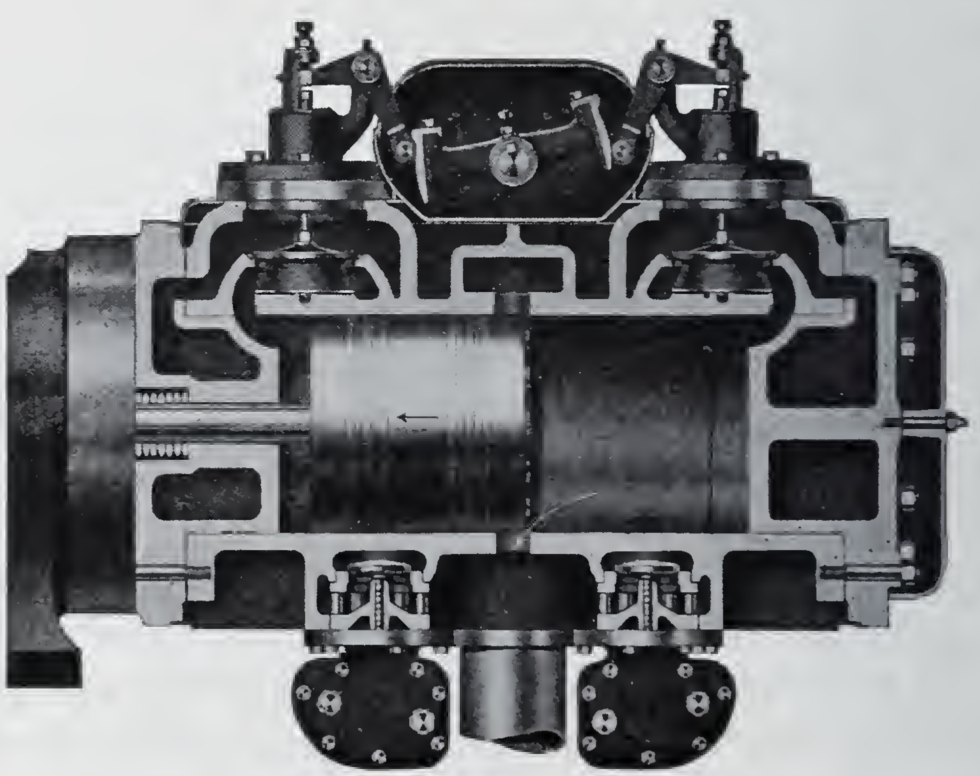


Fig. 15. Section of Single-Cylinder Engine.

exhaust. For the best economy, it was early realized that it was necessary to have poppet-valves which will remain steam tight under varying pressure and temperature conditions and which can be ground in cold.

The Skinner Engine Company employs a patented expansion compensating, double-beat valve which is used on all its uniflow designs, both marine and stationary. In this valve the upper seat is telescopically mounted on the main body which carries the lower seat, and with varying cylinder temperatures, from that of the initial pressure to that of the exhaust steam, this valve will remain steam tight and requires practically no maintenance.

Until about five or six years ago practically all uniflow engines built were of the horizontal type, when limited space conditions in typical engine-rooms warranted the development of a multiple-cylinder vertical uniflow retaining the same essential features (so far as the steam cycle is concerned) successfully used in the horizontal type. Fig. 16 shows a typical three-cylinder installation of 400-kilowatt

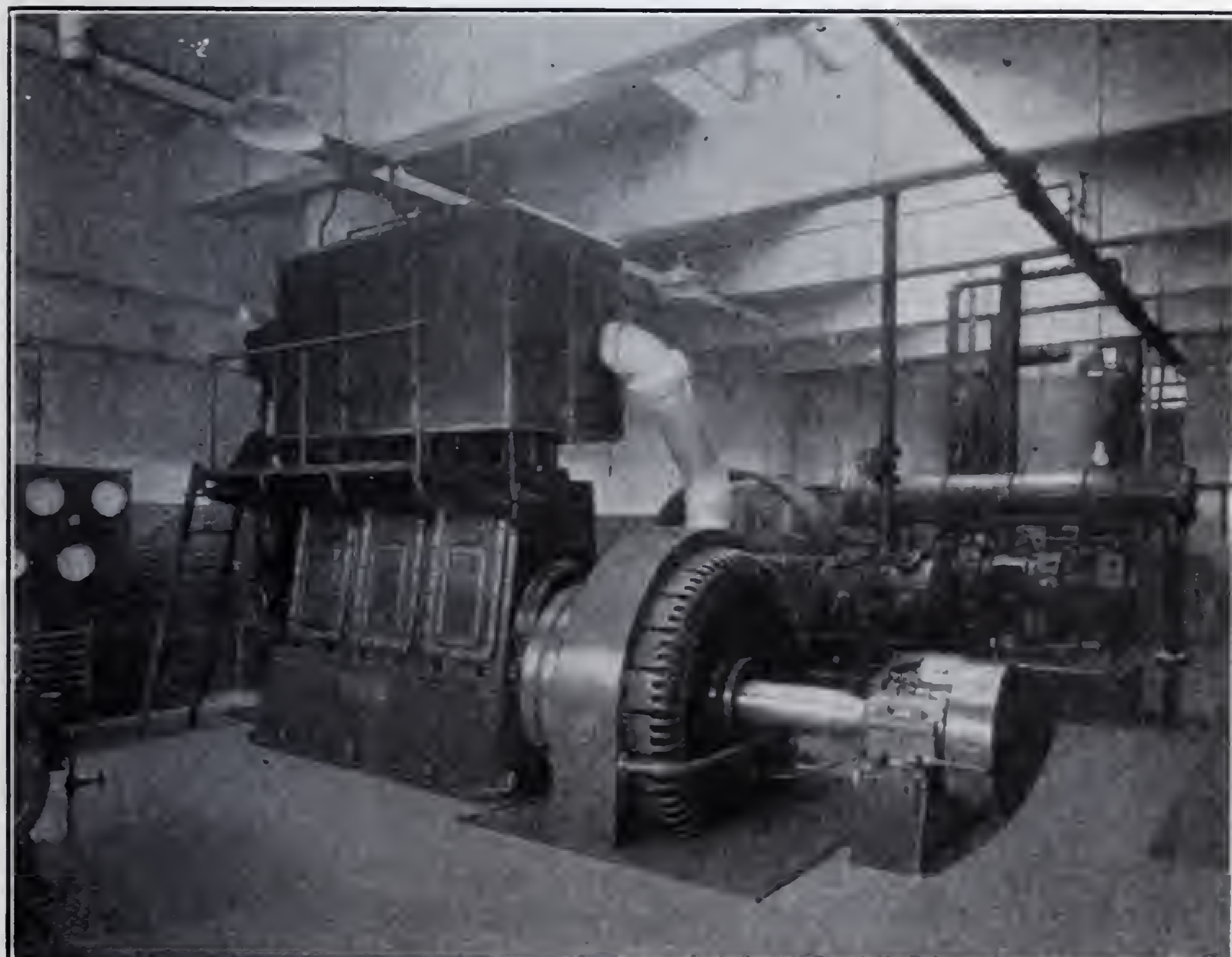


Fig. 16. Vertical Stationary Uniflow Installation.

capacity. This type of engine runs at speeds of about 2½ times that used for the horizontal unit, and a special guide construction, as shown in Fig. 17, indicates the method used for keeping the bore of

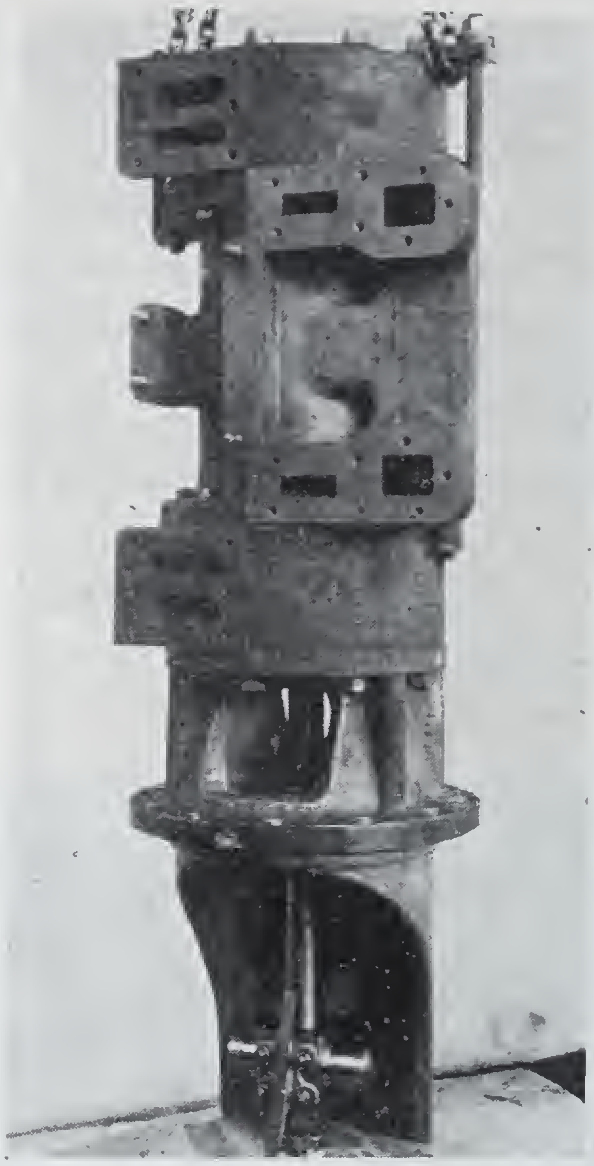


Fig. 17. Cylinder and Guide Assembly.

the guides, which are of the circular type, in perfect alinement with the cylinder and the piston. You will note that the guide is doweled to the lower head which, in turn, is doweled to the cylinder, and the guide casting is supported from the top of the main engine frame by a large flange, and these parts are assembled as a unit and lowered into the frame.

One of the principal developments in connection with the higher speed vertical unit was the valve-gear.

The cross-section of the cam box containing two cam-shafts is shown in Fig. 18. Identical cams are mounted on both cam-shafts, and by means of a cross lever with rollers riding on the cams a compound

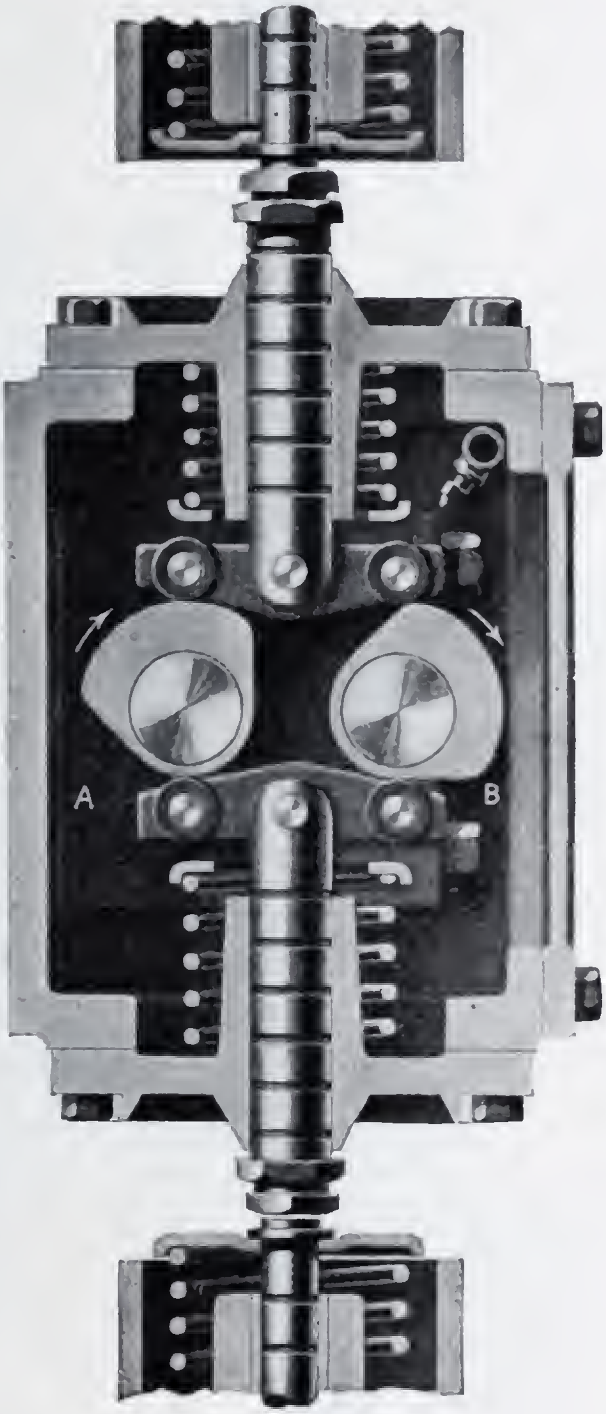


Fig. 18. Cam Action.

motion is obtained for operating the steam-valves. One cam is used to lift the valve, while the other one seats the valve. By advancing or retarding the seating cam-shaft, the cut-off is advanced or delayed, and by gearing the lifting cam-shaft through to the crankshaft, constant lead which is desirable is obtained.

Fig. 19 shows a detail of the cam-shaft assembly, from which you will note its simplicity and positive action. The seating cam-shaft is advanced or retarded by means of worm or helical gears, actuated by the governor for stationary constant-speed use, and by hand or electric control for marine use.

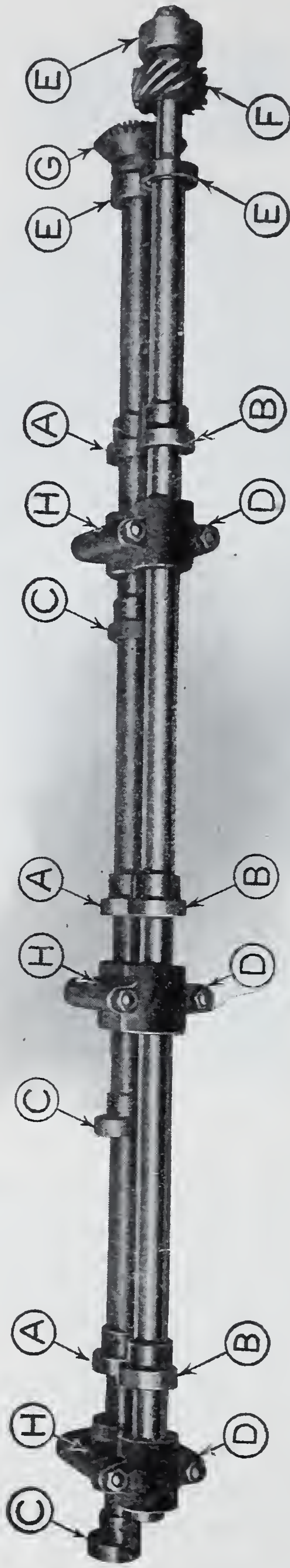


Fig. 19. Cam-Shaft Assembly.

A longitudinal cross-section of a three-cylinder vertical marine uniflow engine, as built for river towboats, is shown in Fig. 20. It is

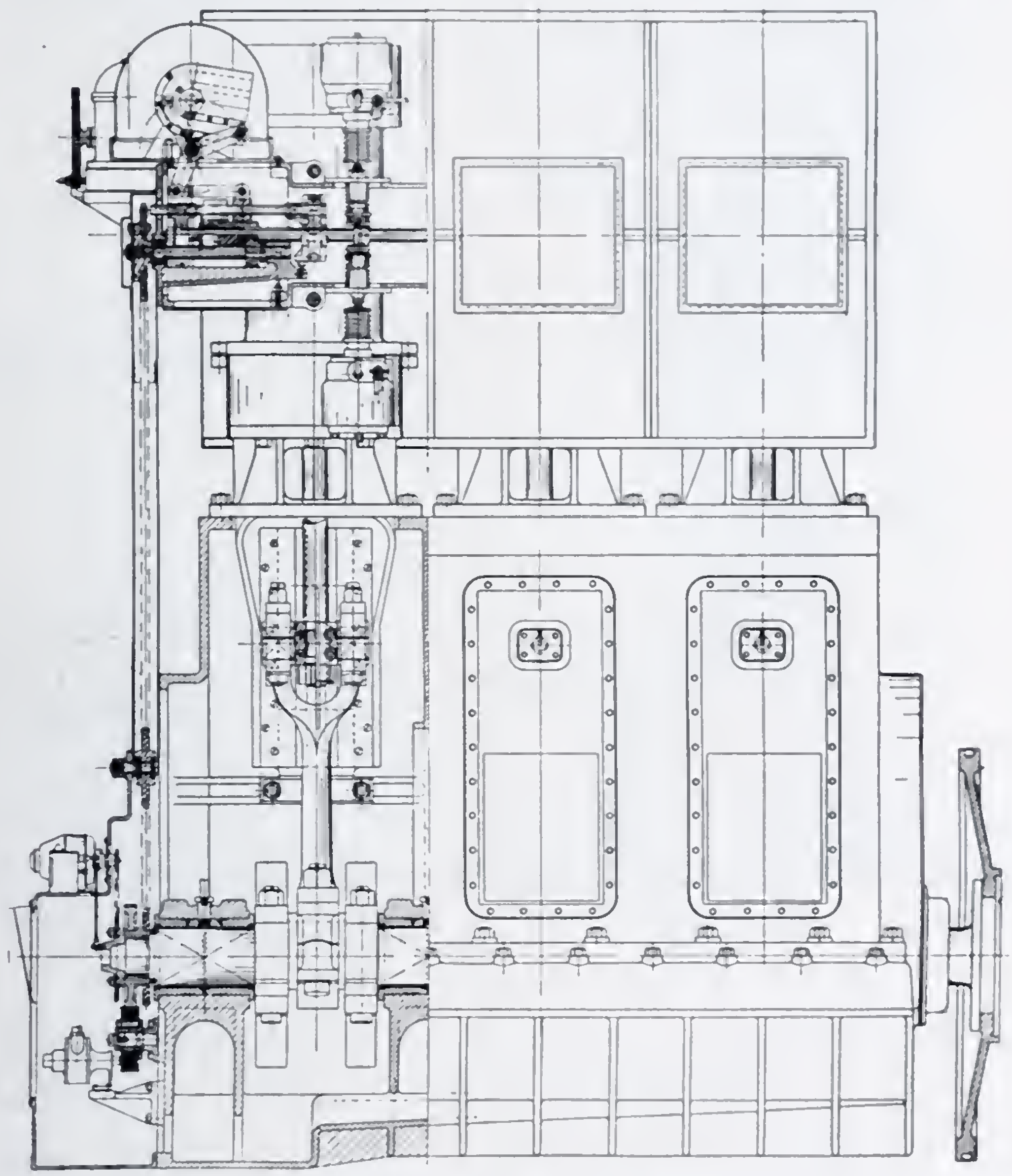


Fig. 20. Section through Engine.

in all essentials the same as the stationary design described in the foregoing, with the exception that the cam-shaft drives are modified to give a reversing engine and valve-gear. When the engine is running in forward drive, one cam-shaft acts as the lifting cam and the other as the seating cam, and for drive in the reverse direction these shafts alternate their functions, and thus give identical cycles running forward or reverse with constant lead and variable cut-off which can be controlled very accurately, and the unit is therefore operated for all conditions entirely by the cut-off (the throttle being left wide open) even when the engine is standing still, under which condition the cut-off is brought to the zero or neutral position. This permits keeping full temperature on the steam-jackets at all times

and gives the maximum economy for all conditions, both normal running and overload condition, and for maneuvering.

Fig. 21 shows a number of actual indicator-cards taken from one of the engines on the steamer *Tennessee.*

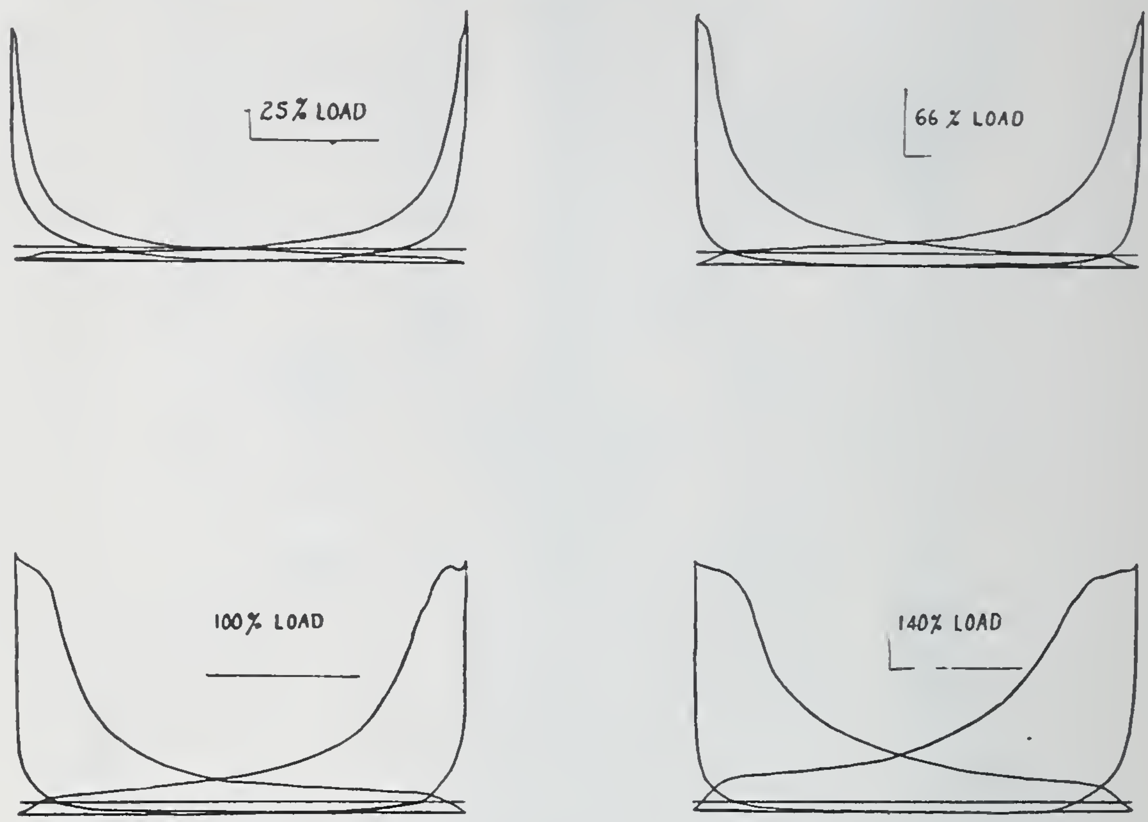


Fig. 21. Indicator-Cards.

Fig. 22 represents a cross-section of one type of engine. In the upper left-hand portion of Fig. 20 you will note a novel arrangement for controlling the helical gears which drive the cam-shafts. This consists of a cam plate which, when tilted in one direction, holds the lifting cam-shaft in a fixed position relative to the crank-shaft and varies the seating cam-shaft. When the plate is in vertical position, the valve-gear is in neutral and no valve lift is obtained, and when tilted in the opposite direction it gives a normal fixed lead and variable cut-off for reverse rotation.

This plate is actuated through a worm-gear drive by a small direct-current, ½-horse-power motor which, together with a special electrical control, can be operated and placed in any position for forward or reverse operation, or for shutting down or starting up, by means of control switches located in the engine-room as well as in the pilot-house. This arrangement gives engine-room control as well as remote control, a master switch being located in the engine-room for throwing the control to either point, and permits operating the

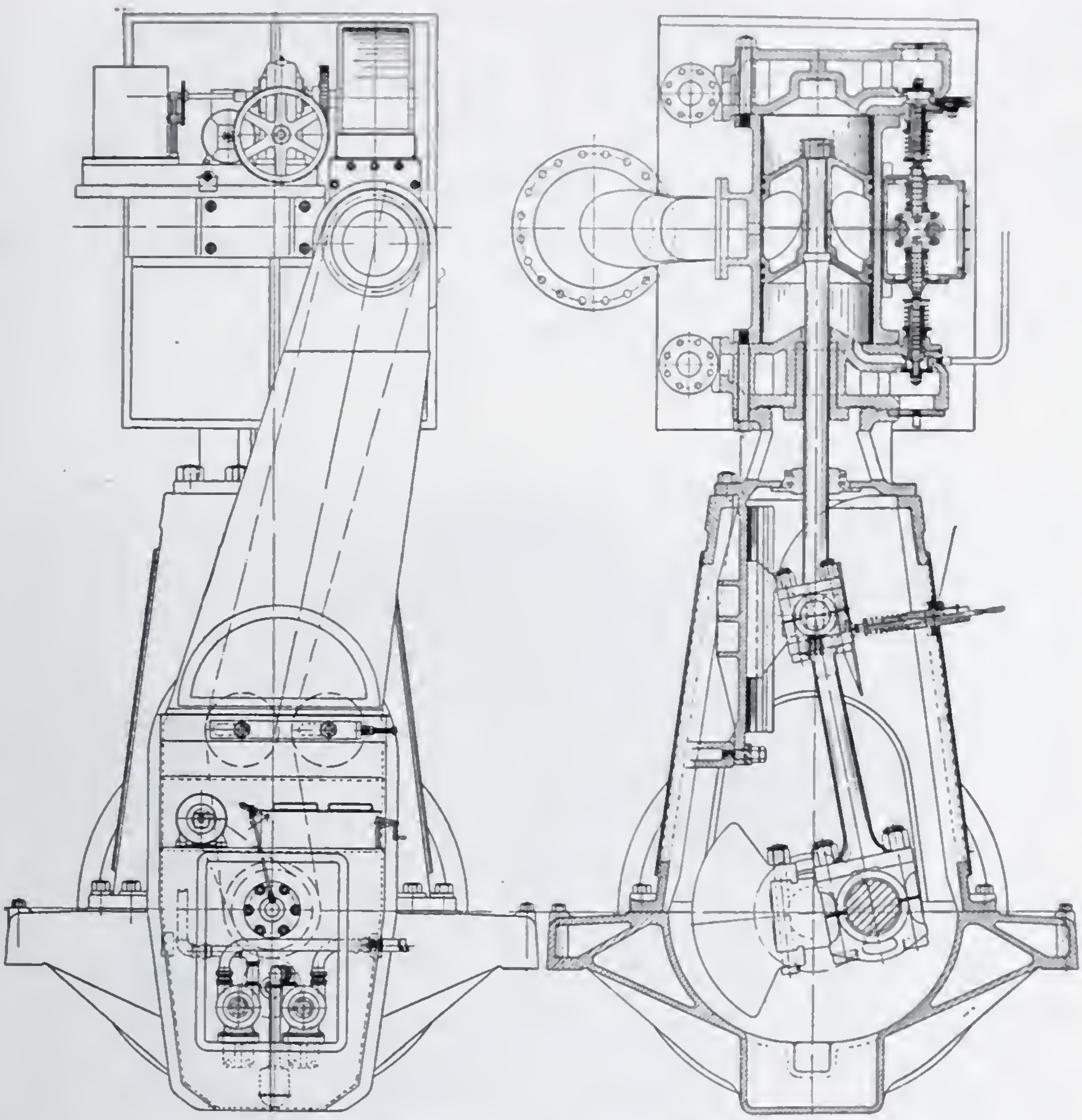


Fig. 22. Section through Engine.

engine entirely on the cut-off with the throttle wide open, eliminating the losses due to throttling for underload conditions, giving full steam temperature in the jackets at all times and maximum economies for all conditions.

The same control by mechanical levers and links can be also arranged as shown on another application in a later figure.

This type of engine has force-feed lubrication throughout, there being two reversing oil-pumps on each engine—one pumping the oil from the dry crank case to a large filtering and cooling chamber, and the other taking the oil from this chamber and pumping it directly into the main bearings, whence it is forced through drilled holes in the crankshaft to the crank-pins, from there through drilled holes to the connecting rod to the cross-head bearings, and from there through drilled holes in the cross-head directly onto the guide. This system

eliminates any water-jacketing of any of the bearings or guides, and gives force-feed lubrication and oil cooling throughout. The loss and replacement of engine oil with this system is negligible, and is due in large measure to accurate and maintained guide alinement, with oil-tight rod packings. A cylinder lubricator is used in addition to this, and we have found by test that the actual cylinder oil consumption averages approximately 13,000 horse-power hours per gallon of cylinder oil.

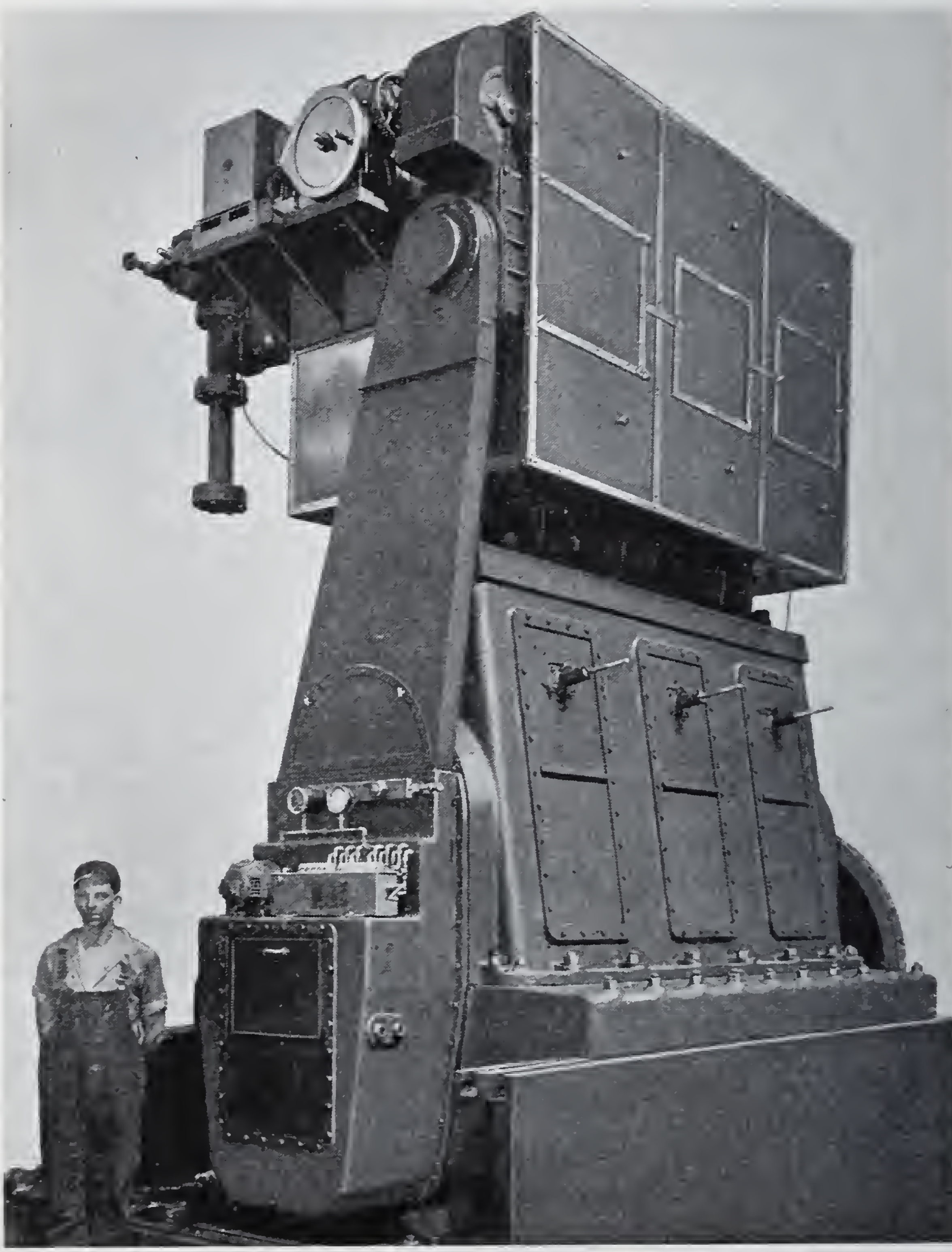


Fig. 23. View of Assembled Engine.

These engines operate normally with total steam temperatures of from 600 to 650 degrees, but have successfully operated with temperatures as high as 700 degrees.

Inasmuch as the bearing loadings are determined by the initial pressure on the piston at the beginning of the stroke, great overloads can be obtained without overstressing the engine, since the valve-gear will give cut-offs up to 75 per cent., whereas normal loading requires only eight to ten per cent.

A forward and inboard view of the completed starboard engine on the steamer *Tennessee* is shown in Fig. 23, and you will note at the top the mounting of the electric control actuating the cam-shaft through the reversing cam mounted in the semicircular housing near the top, with a rotating indicator on the outside showing the degree of cut-off in forward or reverse. The cams are driven by heavy roller chain from the main crankshaft, with an arrangement of tightening idlers which does not disturb the lead setting of the valve-gear and can be adjusted while running. Indicator reducing motions are supplied as shown, mounted on the doors, which close up the main frame, and each door is supplied with a sliding inner door for ready accessibility to the crank, cross-head, and main bearings.

As regards the uniflow application to stern-wheel drive, Fig. 24 indicates a pair of cylinders which were mounted on the steamer

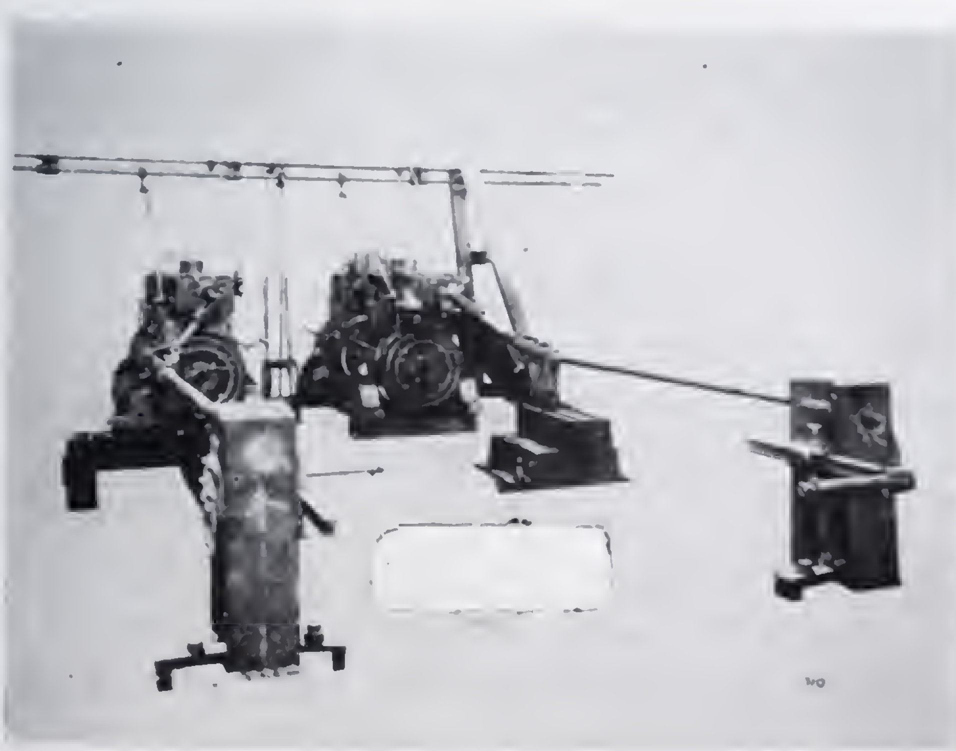


Fig. 24. Stern-Wheel Engine.

Plymouth, using the old guides, cross-head and pitmans, and stern-wheel shaft, and replacing the conventional type of counterflow cylinder. In this case, the valve-motion was taken from an arm, pinned through the body of the pitman. This pin rotates with an elliptical motion, the center of the ellipse coinciding with the cross shaft in the pitman gear-box shown. This drives a longitudinal shaft to a pair of Hooke's joints mounted just aft of the main cylinders. The angle of these joints is set to correct the varying angular movement of the longitudinal shaft which derives its motion from the elliptical movement of the pitman, and corrects this movement to a uniform angular motion in synchronism with the wheel shaft, through each pair of Hooke's joints, and which also serve as couplings for transmitting the pitman motion to the valve-gear case.

With the Hooke's joint arrangement, the upper joint on each cylinder drives a shaft in the cam boxes which are mounted above the cylinders. Two control levers are connected to the helical gears in the cam box—one lever being used for varying the cut-off in forward and the other lever being used for varying the cut-off in reverse. The levers are interlocking so that one lever can not be moved unless the other one is in the neutral position. With this arrangement complete control is obtained without varying the throttle opening, which is left fully open at all times, with full steam pressure on the cylinder and head jackets.

This particular set of cylinders was supplied for non-condensing operation, and the flexibility of maneuvering and uniformity of cards on both cylinders in forward and reverse, from short cut-off to extreme long cut-off, are shown in Fig. 25. These cards indicate the accuracy of the cut-off control, the accurate balance of the head-end and crank-end cards, and the uniformity of cards on both cylinders, together with full initial pressure in the cylinders; and the exhaust stroke shows exhaust pressure in the cylinders which is obtained by ample exhaust-valve area at all cut-offs or settings of the gear, together with quick opening and quick closure, from no lift to full lift. These characteristics are all typical of the type of valve-gear discussed in the foregoing, and give much higher volumetric efficiencies than either the so-called "California" gear commonly used on old stern-wheel river boats, or the piston-valve or slide-valve frequently used with varying strokes and slow motion.

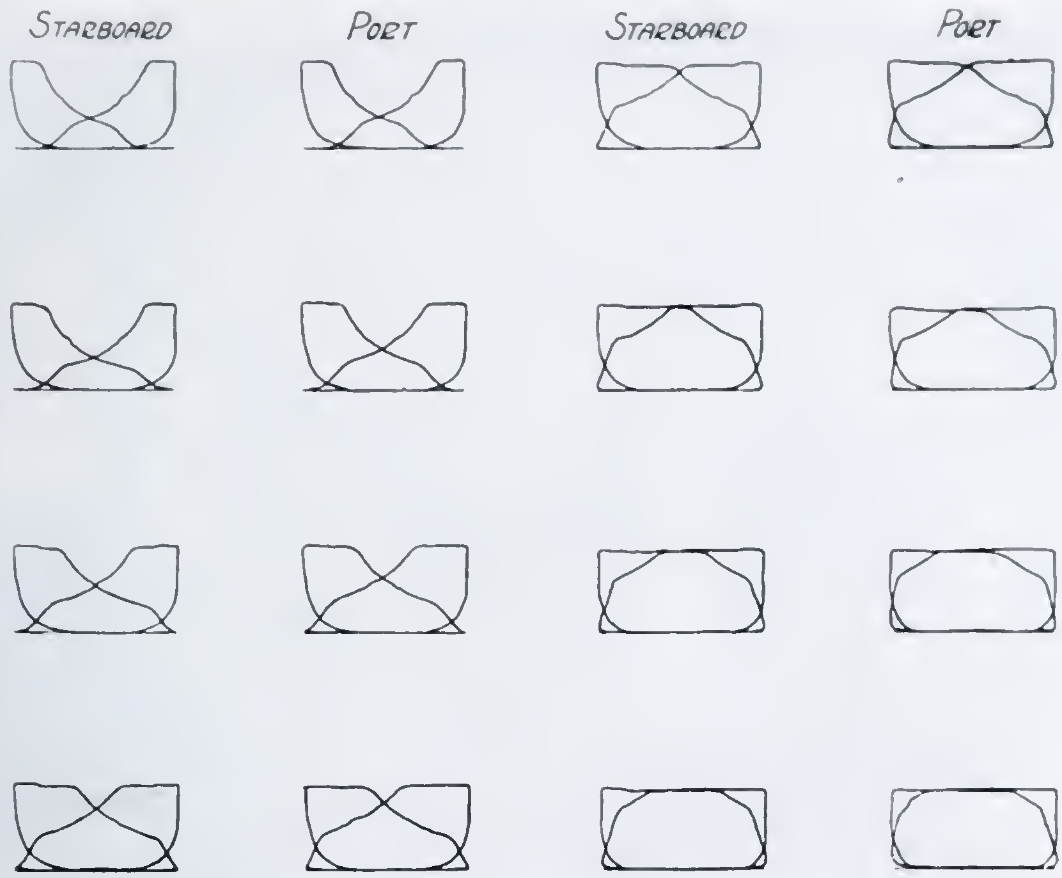


Fig. 25. Indicator-Cards of Non-Condensing Engine for Stern-Wheel Boat.

This engine was applied on a non-condensing coal-fired steamer, and the mere application of the uniflow principle, together with efficient valve areas and steam-tight valves, and steam-jacketed cylinders, resulted in a fuel saving of approximately 35 per cent., together with increased horse-power.

The condensing uniflow has also found an application on dredges and sand diggers, and several dredges of the digging ladder type are propelled by uniflow engines of the standard stationary horizontal type, driving the screens and ladders on the dredge by means of a belt. An interior view of one of these dredges, showing two of these engines in service, is shown in Fig. 26. These engines are non-reversing, but are equipped with a hand-operated three-way valve for reversing the engine or moving it a few revolutions in either direction, which for obvious reasons is desirable with this particular application.

In conclusion, let me state that all of these engines are conservatively capable of operating at higher temperatures and with considerable superheat. This is possible by reason of proper cylinder design and proper materials in the cylinder casting, the type of inlet and exhaust valves used (all of the poppet-valve type), and the design of

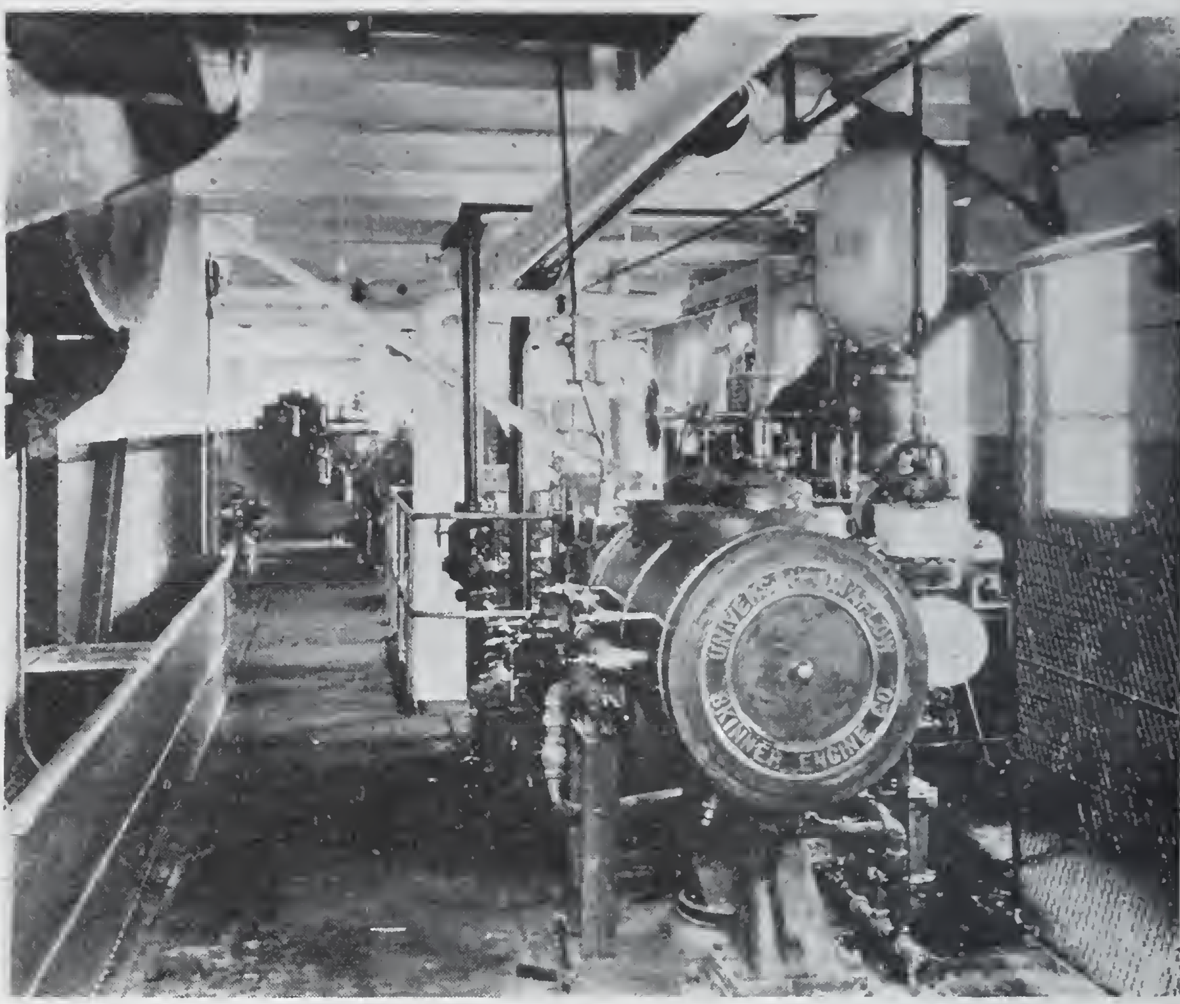


Fig. 26. Interior of Dredge, Showing Engines in Service.

the valve-gear. It has been our experience that marine engineers do not appreciate the value of superheated steam and the material reduction in steam consumption which can be obtained by its use. Their reluctance to the use of superheat probably originates in difficulties with engines of older design, made of materials not suitable for high temperature work, with slide-valves of various types, which are difficult to lubricate and keep steam-tight under high and varying temperature conditions.

While the locomotive is still using piston-valves and experimenting at present with poppet-valves, the addition of superheaters to locomotives in the last 25 years has proved to be the greatest single advantage applied to locomotive design, and we feel quite strongly that it will prove the same in the marine field. The gain in economy has been demonstrated by numerous tests to be approximately 12 per cent. for each 100 degrees of superheat applied, and, inasmuch as superheat is obtained with small additional fuel expenditure and results in increased boiler efficiency and a minor increase in boiler weight, we see no reason why it should not be more extensively used

in marine work, provided the prime movers actuated by this steam are of suitable design and will perform reliably with the higher temperatures.

J. A. DENT, *Chairman:* I regret to say that Mr. J. C. Barnaby, who was to have presented a discussion of the Diesel engine, is unable to be here on account of illness, and so the paper on the Diesel engine will be presented by Mr. J. L. Yates.

J. L. YATES:* If I may, I would like to amend the introductory remarks of our Chairman and say that Mr. Barnaby's illness has prevented his writing a paper. It therefore follows that your speaker must talk extemporaneously. Unfortunately, we do not have sufficient comparative information on river towboat applications to make a comprehensive paper, but I think that what has been done with deep-sea vessels is applicable to the river boat, and I can show you some slides which I hope will be of interest.

I happen to be connected with a corporation that manufactures both steam machinery and Diesel machinery. We are vitally interested in the improved economy of both types of equipment, but the rapid rise in Diesel-engine tonnage can not be denied. Information published by *Motorship,* in October 1931, indicates that the Diesel-engine tonnage registered in the first six months of 1931 is greater than the steam-engine tonnage registered in the same period. The *Bulletin of the American Bureau of Shipping,* for July-August 1931, lists 31 self-propelled vessels building as of July 1, 1931. Of these 31 vessels, 23 were Diesel-engine driven, with a total horse-power of 20,745, as against seven steam vessels with a total horse-power of 10,200. Compared on the basis of gross tonnage, the Diesel-engine vessels totaled 11,594 gross tons, as compared with 6891 gross tons in steam vessels. The odd vessel making the total of 31 listed is a gas-electric vessel. The Diesel-engine vessels in this list vary from 150 to 3000 horse-power, with a majority around 750 to 1000 horse-power, which is comparable to the power in the larger river boats.

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Right now we are in a period when there is not as much freight moving as we would like. If we take a trip along the Atlantic seaboard and look over fleets composed of Diesel-engine ships and steam ships, I think we will find the steam ships tied up. The United States Shipping Board fleets have been operated by various operators. When they come out for lease there is a scramble for those with Diesel engines. That does not happen with steamers. True, many of these steamers are not the last word in steam, but this is also true of the Diesel power. The Diesel engines of the United States Shipping Board fleet were among the first big marine engines of this type built in the United States, and they were built with the idea of giving American manufacturers a chance to develop large-size marine Diesel engines. Going outside the United States, almost every ship in Japan is Diesel-engine driven. Why? Not because Japan wants to spend money and experiment, but because she knows Diesel ships are profitable. The same is true on practically every freight line in the world.

It is true that in this river work the price and availability of coal put the Diesel engine up against a hard proposition; but, even in this particular case, I think there will be a gradual change to the Diesel engine.

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Some research work at Pennsylvania State College has afforded a great deal of very valuable information about the performance of combustion chambers of Diesel engines. As Mr. Yates pointed out, the time during which the combustion takes place may be a considerable part of the total cycle; but, since that combustion takes place when the piston is right at the end of the stroke, the motion of the piston is very slight, though the time involved may be a considerable part of the total cycle. If you make the indicator motion just 90 degrees out of phase with the motion of the piston you will get a very

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On the steamer *Plymouth,* which was an old ship with horizontal return tubular boilers of the common river boat type, burning coal and running non-condensing, there were no accurate tests made. Their operators, however, did run some rough tests showing an improvement in economy of about 30 to 35 per cent. over the old engines, with an increased horse-power of approximately 15 per cent.

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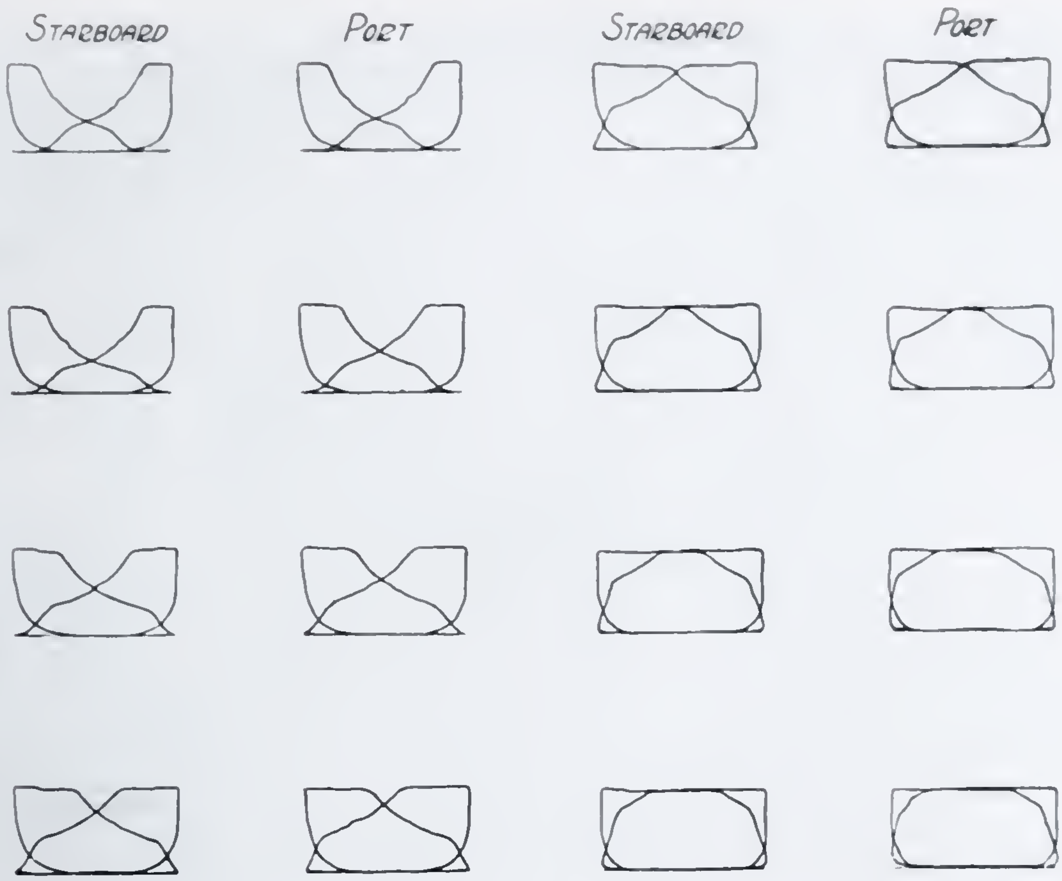

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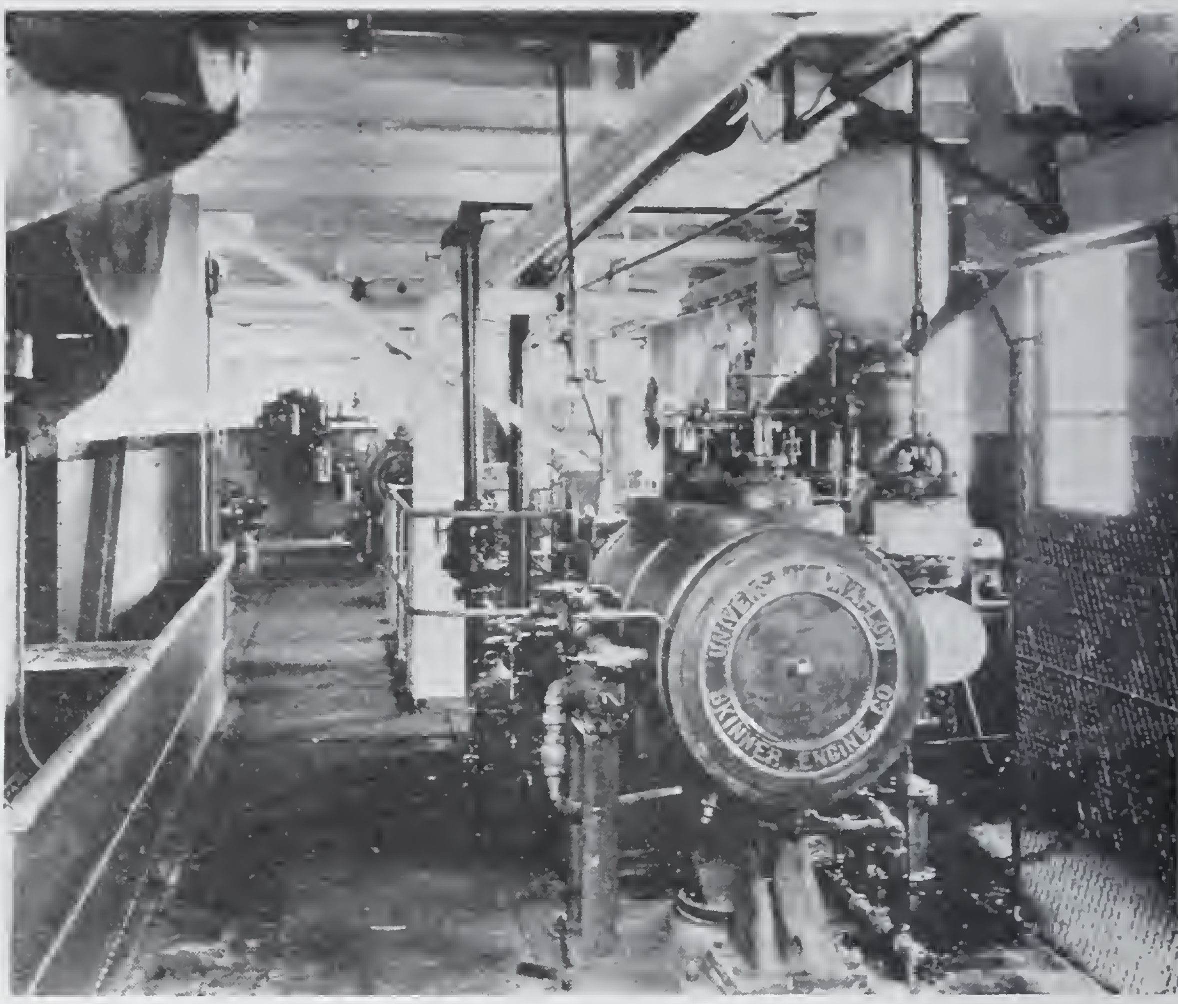

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was in favor of a pulverized coal-burning plant; but, in view of the fact that coal from Alabama was felt to be the only suitable coal along the river for use in a pulverizing plant, and also because pulverized fuel or coal in any form requires equipment for loading and unloading and is always more or less dirty, the decision was in favor of oil-burning steam. The market value of boiler oil reported by various dealers and supplying firms along the river showed a cost about one-half that of oil for Diesel engines. Furthermore, as regards the overall steam rate, which is known approximately only, I believe this to be higher than necessary on account of some of the auxiliaries. Our tests showed some of these auxiliaries, which we had opportunity to check roughly, to be higher than normal.

On large, modern ocean-going plants, using pressures of approximately 400 pounds with 750 degrees superheat (plants on the inland waterways, so far as we know, have not exceeded 300 pounds), there are many records showing overall steam rates as low as 0.63 pound of oil per shaft horse-power for all purposes, as compared with approximately 0.45 pound of oil per shaft horse-power for Diesel plants. The performance of the Diesel plants on some twenty-five ships equipped with Diesel engines shortly after the World War shows an average of 0.52 pound of oil for all purposes.

Considering the difference in fuel costs and the fuel rates for modern steam plants, as stated above, it is apparent that the cost of fuel per shaft horse-power is considerably in favor of the steam plant. The steam plant also has other advantages, such as flexibility, reliability, space requirements, quick reversibility, low maintenance, and lower first cost.

It is true that the Diesel engine from a purely thermal efficiency standpoint is not as yet equaled by modern steam plants, but it is very closely approached in some installations, such as the mercury-vapor plant, which, however, has not yet been adapted to marine service. The first cost, the operating cost, the fixed charges, the maintenance cost, the flexibility, the reliability, and even the labor cost, as indicated by reports published by the United States Shipping Board, are at present on ships of say 1000 horse-power and larger, all in favor of modern, efficient steam-driven ships.

M. E. Bessemer:* Some time ago I saw in one of the Pittsburgh newspapers an article about a system which purported to be an effective method of propulsion of river vessels. It had an endless chain with flat-plate paddles mounted at right angles on it. The chain passed down over a sprocket at the bow, then to the rear under the boat in a longitudinal groove or tunnel, and up again at the stern. By drawing the chain to the rear under the boat, the mechanism would propel the boat forward. Has that idea ever been developed?

J. A. Dent, *Chairman:* Along the same line, has there ever been any attempt to drive by a jet of water through a centrifugal pump or something of that sort?

T. R. Tarn: I have no first-hand knowledge of any attempts to propel a boat by means of a centrifugal pump. The most common method has been the use of reciprocating pumps in conjunction with nozzles. For the most part, any attempts to propel river craft have been confined to contractor's equipment associated with construction work or pump boats used in days gone by for dewatering fleets of coal barges.

On a number of occasions experiments have been made in propelling a vessel by the reaction of a jet of water pumped through an orifice in the stern. Two jet-propulsion steamers were built by the British government in the 'sixties. One gave an efficiency of only 18 per cent. The other, a torpedo boat, was able to attain a speed of 12 knots. In defiance of the mathematical theory of W. J. Macquorn Rankine (discussed by him in the *Engineer* for January 11, 1867, volume 23, page 25, in which he showed that the greater the quantity of water operated upon by a jet propeller, the greater the efficiency) two experimental boats were built in New York during the early 'nineties at a cost of $200,000. In these a pressure of 2500 pounds per square inch was used in a jet ⅝ of an inch in diameter. As had been predicted, the experiment was a total failure.

As far as we have knowledge, no major experiments have been undertaken to fulfil the requirements of Rankine's theory, and it is our opinion that the real possibilities to be derived from jet propul-

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sion have yet to be given a fair trial, particularly as the use of the now highly developed centrifugal air-compressor is available to handle a less weighty and unwieldy medium for producing the desired reaction. Especially is this method of propulsion desirable for shallow-draft vessels, for it is to be remembered that the propelling force in jet propulsion is the reaction of the stream issuing from the orifice, and it is the same whether the jet is discharged under water, in the open air, or against a solid wall.

[illegible]